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Metal Progress

DEVELOPMENTS IN AIRCRAFT METALLURGY

An Editorial Review

IT IS COMMON KNOWLEDGE that the construction of airplanes has gone through at least three definite stages in the last 20 years. Neglecting the great difference in appearance between the observation planes used during the War (and the exhibition planes precariously flown by barnstorming aviators before that) and the modern scout, the essential fuselage construction has changed from a fabric-covered truss of spruce and piano wire, through an intermediate stage where the truss was welded together of alloy steel tubing, to the present monocoque or stressed skin construction where a metal skin, properly stiffened by interior frames and stringers, carries the bending and shear loads. Wing structures have gone through a somewhat similar evolution as their size has increased in the larger and larger transports. Concurrently an enormous development has taken place in the power plant and its auxiliaries, and the various navigation and control instruments. All of these have, of course, depended on the ability of the metal industry to prepare uniformly reliable materials of construction, often with difficult combinations of physical, chemical and mechanical properties.

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THE PROBLEM of building reliable aircraft and their power plants is made especially difficult by the severe requirements as to performance, coupled with the necessity of building to a minimum weight. In his endeavor to keep the weight low, the designer is forced to use the very minimum factor of safety; this not only requires the use of materials of high physical properties but demands the highest quality and uniformity that is ever obtainable.

Testing engineers have devised various tests for controlling the quality of materials, but the exacting requirements of aircraft work have forced metallurgists in that industry to recognize the need for more accurate chemical analyses and more discriminating and thorough physical tests. Tension, impact, hardness and endurance tests, deep etchings, and microscopic examination, all when properly performed are satisfactory means of checking the quality and adaptability of the material furnished. However, these tests can only be made on supposedly representative samples of a large quantity of material. It is impractical by these methods to test every part of an engine or airplane, for in so doing the part would be destroyed. Even proof tests of assemblies are very expensive and time-consuming.

Development of the magnaflux method of examining steel parts for the presence of defects has been one of the most valuable contributions to this problem, and it is being rapidly adopted by manufacturers of engines and aircraft and is in use at many overhaul stations. The method is proprietary and consists of magnetizing the part so as to cause local poles to form at the edges of a surface defect (or one slightly below the surface), meanwhile immersing the part in a suspension of finely divided iron powder. The local poles collect a fine growth of iron "whiskers" plainly showing against the clean surface of sound metal.

The number of parts taken from service after such a test is surprising. Cracks have been found in crankshafts, connecting rods, piston pins, gears, valve springs, valves, cams,

engine mounts, and all types of welded fittings of the airplane. Sometimes these cracks were a development of an undiscovered smaller crack, present when the part was put in service; in other cases the crack is a fatigue crack developed entirely by service, but which might be due to poor design, defective material, or overloading. Without the use of the magnaflux it would be practically impossible to detect these defects and they would no doubt lead to failure in service and possibly result in loss of life. Fortunately the test offers possibilities of calibrating to indicate only those defects that are detrimental, and in its practical commercial application it should, of course, be so used.

* * *

SINCE ANALYSIS of the structures of large bombers and transports will show that more than three-quarters of the weight is aluminum and its strong alloys, mention should prominently be made of recent developments in this field. Aluminum alloys have, of course, been used for a long time in the aircraft industry and account for much of the success obtained in the construction of light, durable planes and motors. The alloy known as duralumin, which for a long time was *the* high strength alloy of the wrought type, has now been surpassed. By increasing the magnesium content, and modifying the programs of cold work and heat treatment, the average or typical yield strength of sheet material has been increased from 35,000 to 43,000 psi. and the tensile strength from 58,000 to 65,000 with no loss in ductility. An article by Mr. Bossert on page 42 of this issue gives some interesting facts about this new alloy, 24S.

One feature which has been helpful in extending the use of aluminum is the fact that the strong alloys can be fairly readily and cheaply extruded in shapes of complicated cross-section. Many dies have been prepared for shapes especially adapted for integral parts of stressed-skin structures, with obvious economy to the aircraft builder who otherwise would be hard put to construct equivalent members of sheet and simpler standardized shapes.

Alclad — strong, light alloys covered with a thin layer of quite pure aluminum — is not a new material, but its growing use warrants mention. Its durability is clearly shown by the metal-clad airship ZMC-2 (in which the gas bag is made of unprotected Alclad 17S-T sheet only 0.0095 in. thick) which has been in continuous service since the summer of 1929 and is still in very satisfactory condition. The aircraft designer is therefore more willing to accept the increased weight due to the pure aluminum coating as a guarantee of the mechanical integrity of the sheet without the cost (and weight) of periodic painting.

A more recent development of an alloy for forging shows a minimum guaranteed yield strength of 50,000 and a tensile strength of 65,000 psi. with an elongation of 10%. While sand castings of aluminum are used in many structural joints, the trend is toward forgings whenever enough can be produced to warrant the construction of dies. Improved forging alloys and processes have produced parts which at one time were considered impossible to manufacture by this process. Aircraft pistons are no longer made in the foundry but are forged, with the resulting greater strength and freedom from blowholes, shrinks, cracks and other defects that are always a menace even to the best regulated foundries. In many engines cast crankcases have been replaced by forged ones that can be relied upon for twice the tensile strength.

* * *

SO FAR, all stressed joints in the strong aluminum alloy sheet are made by riveting. Rivets of the duralumin type (Alloy 17S-T) had to be driven within one half hour after quenching or else prevented from aging by holding them at low temperature. A modified alloy known as A17S is now available for rivets that can be driven without cracking after the material has aged. This is accomplished at a loss of about 15% in shear strength, which obviously can be easily overcome by using the next size larger rivet. Their use is a welcome convenience in the shop.

A great demand exists for rivets which can be driven from one side, without bucking-up, where clearances are tight or where repairs must be made on operating aircraft. This has been supplied by so-called Rivnut, a rather long rivet, with an axial counterbore ending in an internal thread. The protruding inner end of the rivet is upset by a simple air squeezer which simultaneously pushes against the flat head from the outside, and pulls up the inner end by means of a piston rod screwed into the internal thread in the rivet. Somewhat similar devices made of steel are commonly used for rivets in difficult joints in automobile frames.

The perfection of spot welding of aluminum alloys may offer many constructional advantages. At the present time it is limited to non-structural parts of aircraft. However, the future may see the perfection of roll welding, which produces a welded seam and therefore results in a much stronger joint. In its present form this process consists essentially of passing the parts to be joined between two rollers that exert considerable pressure at the joint and transmit the correct welding current. Riveted joints in aluminum which must be water-tight (as in pontoons and hulls of flying boats) are difficult to make tight and keep tight, requiring generous use of rubberized fabric or pasty compounds at faying surfaces and under rivet heads. Seam welded joints would be especially desirable for such items.

* * *

USE OF MAGNESIUM alloy castings has greatly expanded in the last three to four years, due principally to the saving in weight offered. These castings, of magnesium with aluminum, manganese and zinc, properly heat treated, have been used for crankcases, landing wheels, oil pans, brake assemblies, starters, control parts, instrument housings, distributors and various other accessories.

The use of magnesium alloys in all forms, cast, forged, extruded and sheet, would be greatly extended if its resistance to corrosion could be improved beyond that which has already been done (principally by modifications in composition). Further protection is obtained by a coating of some kind. In most foundries castings are immediately cleaned and pickled in a chemical bath — a passivating process, done by dipping the part for about one minute in an aqueous solution containing sodium dichromate and nitric acid. This results in a yellow or yellow-red iridescent color, a coating not in itself a strong corrosion preventative, but it does offer an excellent surface to which the paint can adhere. To protect magnesium alloys against salt spray it is necessary to paint them with one coat of zinc chromate primer followed by two or three coats of synthetic resin enamel of phenolic type. A process used in England is to immerse magnesium castings for 45 min. in a boiling solution of potassium dichromate, ammonium dichromate, ammonium sulphate and ammonia.

A promising treatment is the anodic oxygen process, which consists in making the part to be coated the anode in an electrolyte containing sodium dichromate and mono-sodium phosphate. The time required to produce a satisfactory coating is about 30 min.

* * *

CHANGES in the metallurgy of engine parts have been numberless; merely some recent ones of outstanding importance can be cited.

Improvement in technique in the aluminum casting foundry has contributed considerably to the success of the high powered, air cooled aircraft engines. In addition to the ability to make sound castings free from defects for such parts as crankcases and cylinder heads, it has been necessary to cast heads with extremely deep and thin fins closely spaced. The additional cooling area provided by the large number of deep fins has made possible the construction of air cooled engines developing over 1000 hp. In some cases it has been necessary to cast aluminum alloy fins spaced five to the inch, about $\frac{1}{16}$ in. thick and 2 in. deep. This will be recognized by every foundryman as an extremely difficult requirement.

Copper-lead bearings have recently been brought to general attention by their increased use in the automotive industry. However, this material is old to the aviation industry, it having been used for a long time as a lining for a steel shell which forms the master rod bearing on radial engines. With the increase in speed, bearing load, and operating temperatures, it has been necessary to improve the life and quality of these bearings. This has been done by producing a more fine and uniform dispersion of the lead. There are several methods of bringing this about such as chilling, deoxidation, and the addition of minor amounts of special elements, the exact function of which is not in all cases clearly understood.

Excessive wear of cylinder barrels on large aircraft engines has been overcome by one manufacturer by using a nitralloy steel barrel with nitrided bore. This has resulted in a great saving in overhaul, since the life of the nitrided barrel now practically equals the life of the engine. Wear on the stem of the soft, high chromium-nickel valves has been mitigated by a thin nitrided case; the steel is not of the nitralloy type but will assume a very thin case after considerable time in a nitriding furnace. The expense is warranted by the increased life of the valve stem. Another trend in engine parts and aircraft accessories is the adoption

of nickel-chromium-molybdenum steel (such as S.A.E. 4345) on account of its deep hardening properties and excellent ductility and toughness at high strength.

* * *

IN ORDER to meet the future demands for quality and performance, the aviation industry will require all the developments that metallurgy can offer. Such a valuable corrosion resistant material as K Monel, which can be heat treated to a wide range of physical properties, will no doubt find important uses. Due to its negligible magnetic susceptibility it should have not a few useful applications in proximity to the compass. Present experiments indicate possibilities for use as tierods, roller chains for retracting the landing gear, and propeller blade bushings.

Collector rings and exhaust stacks must withstand high temperature, vibration, corrosion, abrasion and be made of a material that readily lends itself to forming and welding. The most satisfactory material at present is the 18-8 type of stainless steel made to special welding requirements. Preliminary tests on Inconel for this purpose indicate that this alloy will also be a satisfactory material, as well as for carburetor preheaters, and cabin heaters.

* * *

AN INTERESTING discussion of the suitability of stainless steel for the aircraft structure is carried on page 46 of this issue, and of heat treated alloy steel on page 37.

It must be admitted that the aircraft industry as a whole has not shown very much interest in steel as a structural material; in fact, even the excellent chrome-molybdenum "aircraft tubing," once so popular for welded skeletons, seems now to be at a standstill, except in its use for landing gear and engine mounts. Since the trend appears to be toward larger and larger aircraft, rather than quantity production of smaller ships, this attitude may change, for high strength alloy steel and stainless steel are both at a real disadvantage when compared with aluminum in lightly stressed members. Such members fabricated in steel sufficiently small or thin to take full advantage of the high strength may be of such light gage as to be damaged in handling. The more bulky aluminum when fabricated in the same shape is therefore stiffer and appears far less fragile.

Since designers are beginning to use yield strength or proportional limit to compute safe stresses rather than ultimate strength, much has been said about the low proportional limit of cold-rolled stainless steel of the 18% chromium, 8% nickel variety. (In passing it may be remarked that heavy cold work seems to put any material into a plastic condition in the sense that a precisely measured stress-strain curve starts bending away from proportionality at a low load, but that has not prevented an excellent service record from being achieved by piano wire, bridge wire, and hoisting cable generally.) Heat treated, high chromium steel has a high and well-defined proportional limit, but unfortunately it must be protected against stress corrosion or season cracking, and welded joints lack ductility. Recent investigations indicate that a high range of elastic action may be achieved in 18-8 (which does form and weld excellently) by a proper selection of analysis, anneal and cold work. By this means, as Dr. Krivobok and his associates have shown, it will attain only 0.01% permanent set at 100,000 psi., in varieties with 185,000 psi. ultimate and 9% elongation — truly an excellent combination.

Another interesting possibility has been developed under Dr. Arnstein's direction at Goodyear-Zeppelin, in the form of a low carbon 18-8 containing about 0.5% titanium. This is cold rolled to 160,000 psi. ultimate, and is then easily cut, bent, and otherwise fabricated. Complete structures are then aged at 900°F., which not only relieves fabrication stresses, but also induces a high yield strength.

With these new varieties of stainless steel at their command, with a continually increasing mass of accurate information on the manufacture, fabrication, and properties of the older alloys, and with a keener realization of the commercial possibilities of these relatively new stainless steels — truly noble metals — the producing industry can be relied upon to present its wares much more vigorously to the aircraft builders. Intelligent salesmanship can now be expected as a matter of course, for if there is one thing that the depression has taught the steel producers, it is that it pays to have an understanding of their customers' metallurgical problems. Since there is a great and growing market in future airships, it is sure that aluminum — good as it is, and promoted as well as it is — will not be allowed to pre-empt that market by default. And that is as it should be, for it is our prime interest to help the right metal find its way into the right application.

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Heat treated alloy steel —the lightest material of construction

A RECENT SYMPOSIUM on the role of the metals in transportation, by the American Institute of Mining and Metallurgical Engineers, turned out to be a discussion on lightness and methods of saving weight! Lightness is, of course, the very life of the aircraft industry. To save a pound in the weight of an airplane improves its performance and increases its pay load (and therefore its earning capacity) and is worth anywhere from \$1.00 to \$100 in the cost of the ship — a conservative value in modern transport planes might be \$15.

Somewhat less striking but grossing larger figures are the economies obtainable by eliminating useless weight in other vehicles of transportation such as the bus, the truck, the trolley car, the passenger railroad car, the freight car, and even the ocean liner. To aircraft belongs the credit for awakening other industries to the economy of light weight construction and for leading the way in materials and methods.

Alloys of aluminum and magnesium, being of low specific gravity, are usually referred to as "light metals" and sometimes are called the "lightest materials" of construction. This is not strictly true. Steel, alloyed and heat treated to high strength, is lighter, where it can be used efficiently, than any of the so-called light alloys.

The Strength - Weight Efficiency — Structural materials, where weight is concerned, cannot be compared on the basis of weight or strength alone. Pure aluminum, for example, is a light metal with specific gravity of only 2.7, but it is nevertheless a heavy material of construction because of its low strength. In this respect it is, in fact, heavier than ingot iron with specific gravity of 7.8, as explained in detail below.

In a structural material, lightness is determined by two principal factors — strength, and weight per unit of volume. The lightness of the finished structure of adequate strength is the real point of interest. This might be termed "structural lightness."

As regards structural lightness, two materials may be compared on the basis of a number obtained by dividing the useful strength value (such as tensile strength, yield strength or endurance limit, expressed in thousands of pounds per square inch) by the weight per unit of volume (such as pounds per cubic inch or, more simply, specific gravity). The number so obtained may be called the strength-weight ratio, and a material of high strength-weight ratio is a light material and has high strength-weight efficiency. These points were brought out by the present author as long ago as 1923 in an article in *Automotive Industries* entitled "Material Strength-Weight Factors."

A few typical materials compared on the basis of tensile strength in thousands of pounds per square inch, divided by specific gravity, are listed on the next page. Pure aluminum is the heaviest while steels are the lightest. The tabulation merits thoughtful consideration.

Such a comparison may be criticized on the ground that engineers are beginning to use, as the proper basis of design in calculating stresses, the so-called yield point or stress beyond which noticeable or an agreed-upon amount of permanent deformation takes place. The highest yield strength recorded by Zay Jeffries in a recent list of wrought aluminum alloys ("Light Weight Metals in Transportation Industry," A.I.M.E., 1936) is 52,000 psi. for cold-rolled duralumin (alloy C17ST, with an ultimate strength of 65,000 psi., elongation of 10% in 2 in., endurance limit 14,000 psi., specific gravity 2.8). Strength-weight ratio based on yield point is therefore 52 divided by 2.8, or 19. For wrought magnesium alloys, the highest yield point given is 35,000 psi., (alloy AM58S, extruded, ultimate strength 46,000 psi., elongation 13%, endurance limit 16,000 psi., specific gravity 1.85). Strength-weight ratio for this alloy is 35 divided by 1.85 which equals 19. On the basis of yield strength, these two alloys have the same strength-weight ratio, which, it may be noted, is not true when ultimate strength is the criterion.

Strength-Weight Factors

Material	Tensile Strength Psi.	Average Specific Gravity	Strength-Weight Ratio
Aluminum, commercial, 2 S	13,000	2.71	4.8
Iron, ingot	40,000	7.87	5.1
Steel, cold rolled	60,000	7.84	7.6
Aluminum, cold rolled, 2 S-H	24,000	2.71	8.9
Steel, S.A.E. alloy	160,000	7.85	20.4
Aluminum alloy, 17 S-T (duralumin)	58,000	2.79	20.8
Spruce for aircraft	10,000	0.435	23.0
Aluminum alloy, C 17 S-T	65,000	2.8	23.2
Steel, S.A.E. alloy, heat treated	190,000	7.85	24.2
Aluminum alloy, 24 S-RT	68,000	2.77	24.5
Magnesium alloy, AM 58 S	46,000	1.85	24.9
Steel, 18-8 stainless, heavily cold rolled	200,000	7.93	25.2
Steel, very high alloy	250,000	7.85	31.8
Steel, piano wire, cold drawn very fine	400,000	7.84	51.0

Now it is quite easy to get heat treated steel which figures to an equivalent ratio. For heat treated alloy steel at the relatively moderate yield strength of 150,000 psi., not an extreme figure in aircraft, we have 150 divided by 7.85 which again equals 19. This steel, therefore, *merely as a raw material of construction,* is as light as the lightest aluminum or magnesium alloy! In aircraft a yield strength as high as 175,000 or even higher is not uncommon. Such steel is therefore much "lighter" than the so-called "light alloys."

Magnesium Alloys — Magnesium alloys are mentioned here because they are included among the light weight structural materials. Their commercial use is at present confined principally to castings, although sheet and extruded shapes are available. In the wrought condition their strength-weight efficiency is comparable with aluminum alloys; their cost is higher and they have less resistance to atmospheric corrosion.

Stainless Steel — Stainless steel, principally of the austenitic type containing 18% chromium and 8% nickel, hardenable by cold work and not by heat treatment, ranks among the lightest materials of construction, having tensile strength as high as 150,000 to 200,000 psi. Resistance to corrosion is its principal advantage, for first cost is high. The necessity for severe cold work makes strong varieties available only in the form of thin strip. It cannot be welded without loss of strength and corrosion resistance, except by the (proprietary) "shotweld" process. It must be formed and fabricated in the hard, springy state — a difficult and costly accomplishment. Modulus of elasticity is low. This, and the ribbon-like construction, cause large deflections under load and quite a tendency toward flimsiness.

Design of transport units is strictly limited by these peculiarities. Nevertheless some excellent results have been obtained, such as in the Budd light weight trains of the Zephyr type, and the Fleetwings aircraft, discussed briefly on page 50 of this issue.

Remarks regarding alloy steels in the remainder of this article refer to the well-known heat treatable, alloy steels of commerce, such as chrome-nickel, chrome-vanadium, and chrome-molybdenum (S.A.E. 4130X). The latter has become virtually the standard alloy steel in aircraft construction because of its remarkable combination of desirable properties. However, there yet remains an undeveloped field for heat treatable corrosion resistant steels that are weldable and capable of fabrication in the annealed condition.

Is Steel, Treated to High Strength, Brittle?
Specimen strips, cut longitudinally from chrome-molybdenum (X-4130) tubing, bent cold. The tubing developed 200,000 psi. ultimate strength and slightly over 180,000 psi. yield strength

Joints — To use materials in the construction of anything but the most elementary objects, joints must be made. The character of the joints has an important bearing on the weight of the finished structure of adequate strength, that is, the structural lightness.

With aluminum alloys it is customary to employ riveting. Electric spot welding is under development, but acetylene welding and electric welding do not seem to be entirely practicable for the strong alloys, although eminently satisfactory for the pure metal. Riveted joints require overlapping at the seams, therefore excess weight. This is equivalent to reducing the strength-weight efficiency.

Riveted joints tend to work loose under repeated stress in service. This results in permanent deformation of the structure, and is equivalent to a lower yield in the material and therefore lower strength-weight efficiency.

On the other hand, the low alloy steels lend themselves to acetylene welding where sections are thin, and to electric arc welding where they are thicker. Of course, they may also be electrically spot or butt welded with great facility.

Well designed and well made autogenous joints are extremely efficient. Very little excess material is required; weight is therefore kept at a minimum. Their rigidity contributes to the stiffness of the structure. They do not work loose in service. Structures with properly welded joints, when subjected to overload, will always bend or break outside of the weld. This is true even when the parent metal has been heat treated to high tensile properties, while the weld metal is of low carbon steel. These factors contribute further to the superiority of steel as a material of structural lightness.

The reliability of structures welded with oxy-acetylene flame has been amply proven in ten years of service in the vital parts of aircraft, particularly in the landing gear and the wing beams. In the landing gear extreme overload and shock must be resisted, while in the wing beams the quality of endurance under vibration or repeated stress is paramount. Correct design and welding practice for highly stressed steel structures is a study in itself. A coarse crystalline structure at the very joint can be refined by the same heat treatment given the rest of the structure. For instance simple butt welds in 4130X steel tubing (low carbon steel welding rod) may test 80,000 psi. in tension, but after a quench and draw will have ultimate strength of 140,000 psi.

This matter deserves careful consideration in other fields than aircraft. It constitutes one of the outstanding advantages of steel over the light non-ferrous alloys.

Stiffness — Stiffness, or resistance to elastic deformation, is frequently a governing factor in design. Since the modulus of elasticity of steel is about three times that of aluminum alloys while its cross-sectional area for equal weight is about one-third as great, the elastic deflection of steel and aluminum members is approximately the same in simple tension or compression. However the conditions usually encountered are bending of beams, flexure of columns, and torque of shafts, and in such circumstances a great deal depends upon whether the member is solid or hollow, and whether its outside dimensions are limited.

By increasing the depth of a beam, the diameter of a column or shaft, or the thickness of a sheet, stiffness and column strength are increased to a much greater extent than the accompanying increase in weight. This means that for equal weight, solid aluminum alloy members are thicker and therefore more resistant to deflection than steel. Consequently, their strength-weight efficiency is increased and lightness is gained. This gives aluminum alloy an important advantage over steel where stressed members are comprised of metal in sheet form.

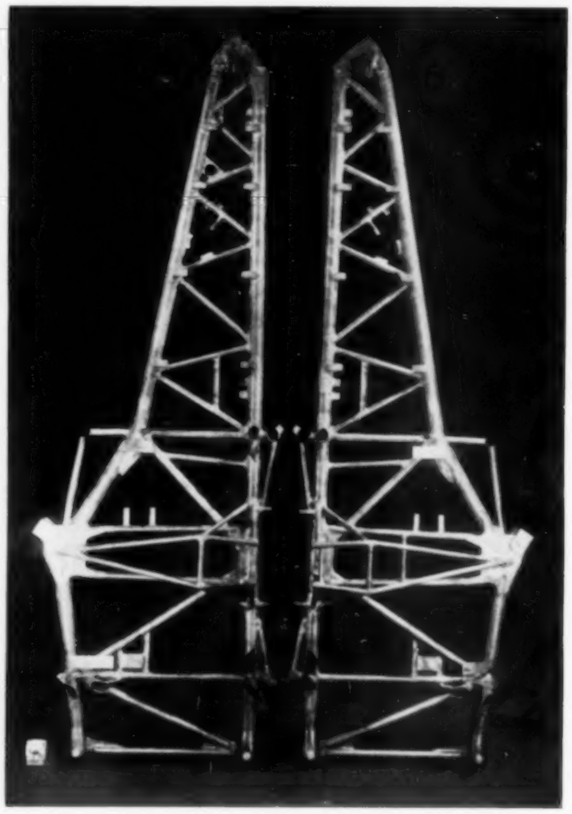
But solid shafts, beams, or columns are very inefficient as regards weight, because the material near the axis is relatively ineffective and represents useless load. Solid members would therefore not be used where lightness is essential in any lengthy member except one working in pure tension.

For hollow members of equal outside diameter or depth, the respective modulus and specific gravity of steel and aluminum alloys tend to offset each other, under elastic deflection, as is true in simple tension or compression, so that members are of equal weight. But for short columns or beams in which unit stress values, rather than elastic modulus, determine design, steel will again be lighter than aluminum alloy, because of its higher strength-weight efficiency.

A limiting condition is found where the wall thickness is slight, so that failure might occur by crinkling or denting (detail failure). Aluminum here has the advantage, being thicker. On the other hand, there are many instances where the greater hardness of steel would give it superior resistance to failure by external injury.

Endurance — In some instances the amount of metal used is determined by endurance limit or fatigue strength.

The endurance limits reported for aluminum alloys are rather low. For example alloy 24S-RT with a tensile strength of 68,000 psi., has an endurance limit of only 14,500 psi., 21.5% of the former. The "endurance ratios" for steels are considerably higher — 40 to 50%, in fact. In aircraft construction, wherever locations subject to severe fatigue are encountered, as at the roots of wing beams, or in engine supports, it has therefore been the custom to use steel fabrications, even where the rest of the structure is of duralumin.



Wing Spars (Stinson) Which Also Are to Carry Landing Gear and Engine Loads — Complex Steel Assemblies Heat Treated to 180,000 psi. Ultimate as One Piece

Fabrication and Heat Treatment — One of the greatest advantages of aluminum alloys is the ease with which they can be cut, machined, or formed with the aid of steel tools, even in their fully hardened state. This advantage is considerably offset by the relatively high cost of the raw material.

Steel structures are often much cheaper to fabricate because welding may be employed, whereas the aluminum and magnesium alloys are virtually limited to riveting. The heat treatable alloy steels are usually fabricated in the annealed state and afterward heat treated.

The round tube is probably the most efficient shape for construction. It has maximum resistance to compression, bending, torque, and accidental external damage, with minimum weight. Tubing may be produced in many special sections, uniform and tapered. A square tube, having well rounded corners, has greater rigidity for certain purposes than the round tube of equal weight and diameter, and lends itself well to the mitered form of joint. All steel tubes are very well adapted to joining by welding and to the construction of complicated joints where several members meet, without unnecessary bulk of material and consequently with minimum weight.

Steel structures assembled by welding tubing into units of convenient size, such as wing beams, landing gear, and fuselage sections, are regularly heat treated without harmful distortion by quenching in oil and tempering to strength values as high as 200,000 psi. This of course requires special equipment, such as vertical furnaces, erected above deep quenching tanks, so arranged that long and spindly members can be hung from one end. Heat treatment greatly improves the strength, toughness and durability of the welded joints, by a refining action on the coarse grain.

The heat treatment of ordinary steel parts such as forgings and machined parts requires no comment here. Certain alloy steels are machinable in the heat treated state at strength values which make them lighter structurally than aluminum or magnesium alloys. Light cuts with high speed steel or carbide tools must of course be used.

These circumstances have been employed to advantage in aircraft construction and may well be utilized in other fields for weight saving, especially where welding, for some reason, is not applicable. For example, alloy steel tubing is heat treated in straight lengths to desired physical properties as high as 200,000 psi. ultimate strength or even higher, then cut, drilled, and assembled by means of fittings, rivets or bolts. Such construction is lighter and may in several ways be preferable to riveted construction in aluminum alloys.

Closure — The writer, having been among the first to work with aluminum alloys in this country, when he served as chief metallurgist of the U. S. Naval Aircraft Factory in the years 1918 to 1925, fully realizes and appreciates their many important advantages and the splendid development through which they have gone. These materials, together with magnesium alloys and austenitic stainless steels, have been vigorously and ably forwarded by their respective producers. However, in the absence of proprietary sponsorship, let us not fail to appreciate and avail ourselves of the outstanding possibilities of the commoner, less costly, and more readily obtainable materials of light weight — heat treatable alloy steels.

Wear Testing

Condensed from The Metallurgist, Oct. 1936

A REVIEW of several recent German articles indicates that experimental testing methods are held to have very limited application, since the wear in service is not so much a characteristic of the material as the conditions of use. Therefore, the relation of a special testing method to the practical processes involved in wear under a particular set of circumstances must be carefully analyzed before any importance can be attached to the results of such a test for acceptance purposes, or even the application of any special series of tests.

B. Kehl and E. Siebel (**Archiv Eisenhüttenwesen** for May 1936) describe an extensive investigation wherein test pieces were hollow rings, butted accurately against each other, and one rotated while the other was pressed against it by a weighted lever.

The two rings were first "run in" until the contacting surfaces were smooth, then cleaned and weighed and the loss in weight in subsequent running determined at various speeds and at various contact pressures, the temperature of the lower fixed ring being measured by means of a small thermocouple inserted into it.

When run dry, the wear of various steels and cast irons increases linearly with the load (provided the temperature is not allowed to exceed 500° F.) until a characteristic speed is reached, whereupon it falls sharply to an almost insignificant value.

Micrographic examination of the worn surface shows that at slow speeds a rough surface is produced, whereas at higher speeds the surface rapidly becomes smooth and consequently wear is reduced; tests in alcohol vapor show that atmospheric oxidation plays only a very unimportant part unless the temperature is allowed to exceed 575° F.

Of course, in practice nearly all sliding contacts are lubricated. According to the hydrodynamic theory of lubrication, the thickness of the oil film depends on the size of the surface, the rate of movement, the absolute viscosity of the oil and the load, as well as on the nature of the bearing surfaces. To obtain a true liquid friction the oil film must have a thickness at least as great as the depth of any surface imperfections, so that the smoother the surface the thinner is the minimum oil film.

If all the other factors are then kept constant the thickness of the oil film depends on the load, becoming smaller the higher the load, until eventually the two metal surfaces touch and the torsional moment increases suddenly, while the local evolution of heat produces a reduction in the viscosity of the oil and consequent wear of the surface of the metal. The load at which this occurs is a characteristic property of a definite type of surface and, therefore, standard surfaces were prepared before testing. Furthermore, 1 mg. of fine emery was mixed with each 1 cc. of oil in the tests.

With oil-emery mixtures the wear increases proportionately to the load at all speeds up to 1 m. per sec., above which it increases suddenly about a hundredfold owing to abrasion by the grit.

Kehl and Siebel claim that tests of the type they carried out give valuable information about wear under certain practical conditions. Tests made with no lubricant correspond to conditions present in brake drums, while those made in oil-emery mixtures may be held to accelerate the conditions of lubricated sliding friction.

While the necessary caution must be observed in assigning an order of merit to materials on the basis of the experimental results, the method of Kehl and Siebel offers a useful means of studying the combined effect of a number of important factors influencing the practical performance of engineering materials.

by T. W. Bossert
Asst. Chief Metallurgist
Fabricating Division
Aluminum Co. of America

Development of 24S alloy extensively used in aircraft

IT IS A FAIR STATEMENT that the aircraft industry provided the initial impulse for the development of high strength, wrought aluminum alloys in the United States. The sustained and continually increasing use of these materials by that industry, together with its constant demands for higher standards of quality, higher mechanical properties, and larger and more precise sizes, has been a predominant factor in establishing the present position of the wrought aluminum alloys of high strength.

In line with this development, the alloy 24S was produced in 1931 as the direct result of demands from the aircraft industry for a material with mechanical properties higher than those then available. It should be of interest, therefore, to trace briefly the history of the wrought, high strength, aluminum alloys.

Prior to the entry of the United States into the World War, the Aluminum Co. of America supplied the United States Navy Department with heat treated, wrought aluminum alloy sheet, at that time designated 17S. These were supplied as the result of the Navy Department's interest in metals for the construction of rigid dirigible airships. This material was required to have minimum tensile strength and yield strength of 50,000 and 24,000 psi., respectively.

Following this preliminary order and during the War, some limited quantities of 17S alloy were supplied, all for use in aircraft. It was not until 1919, however, that the employment of the heat treated wrought aluminum alloys assumed major importance. In that year, the United States Navy began construction in the Philadelphia Navy yard of the airship Shenandoah, using 17S alloy sheet in the heat treated condition for the framework. From that time on, the use of this material for aircraft broadened annually and, as the experiences of aircraft builders expanded, it displaced in an ever-increasing degree the materials formerly used for construction of craft heavier than air.

The alloy 17S is similar to the "duralumin" originally developed in Germany by Wilm in 1909, and sold in European countries under that name. It is so well known today that little need be said to describe it. In the annealed temper (17S-O) it is relatively soft, as shown by the data given in the table, and in this condition it may be readily cut, stamped, bent and formed otherwise. When the alloy is heated to an elevated temperature and then quenched, its mechanical properties are changed considerably — its tensile strength is more than doubled and its yield strength tripled, but this final high strength is not attained until about four days after quenching. Shortly after quenching, the material is still relatively soft, although definitely harder than the annealed material, and it is quite workable. The "age hardening" as it is generally termed, begins immediately after quenching, and proceeds at a gradually decreasing rate for about four days, after which time further change is unimportant.

It was mentioned earlier that the original minimum values for tensile and yield strengths

of 17S-T sheet (the suffix "T" indicates the heat treated condition) were 50,000 and 24,000 psi., respectively. In 1919, these values were raised, as follows: Minimum tensile strength, 55,000 psi., minimum yield strength, 25,000 psi. In 1924, a further change was made in that the minimum yield was raised to 30,000 psi., and at a still later date the minimum yield strength was raised again to 32,000 psi.

These improvements in the minimum specification properties, and in other characteristics — resistance to corrosion, for example — were entirely the result of improvement in the technique of manufacture and more accurate control of manufacturing operations. The mechanical properties of the heat treated, wrought aluminum alloys depend upon a multitude of factors, of which the most important are composition and completeness of the solution heat treatment.

Mechanical Properties of 17S-T and 24S-T
[Typical and Specification]

Material [a]	Tensile Strength Psi.		Yield Strength Psi.		Elongation % in 2in.	
	Typical	Min. Specification	Typical	Min. Specification	Typical	Min. Specification [b]
Sheet						
17S-O	26,000	—	10,000	—	20	—
17S-T	58,000	55,000	35,000	32,000	20	15 to 18
17S-RT	61,000	55,000	46,000	42,000	13	10 to 12
Alclad 17S-T	55,000	50,000	32,000	28,000	18	11 to 16
24S-O	26,000	—	10,000	—	20	—
24S-T	65,000	62,000	43,000	40,000	20	12 to 17
24S-RT	68,000	65,000	53,000	50,000	13	10 to 12
Alclad 24S-T	60,000	56,000	40,000	37,000	18	13 to 16
Alclad 24S-RT	62,000	58,000	49,000	46,000	11	8 to 10
Tubing						
17S-T	65,000	55,000	45,000	40,000	22	12 to 16
24S-T	70,000	62,000	50,000	40,000	22	12 to 16
Extruded Shapes						
17S-T	58,000	55,000	36,000	30,000	16	16
24S-T	65,000	57,000	46,000	42,000	16	12

[a] In designating the conditions of the various alloys, the suffix "O" indicates the annealed condition; "T" heat treated, quenched and aged at room temperature; "RT" heat treated, quenched, aged at room temperature, then cold worked.

[b] Minimum elongations vary with thickness.

While the chemical composition of the metal in the melting furnace or crucible may be exactly as intended, segregation in the cast ingot may produce measurably different compositions in different regions of that ingot and, therefore, the finished product. Continued study of the mechanism of solidification of chill-cast aluminum alloy ingots, and application of the fruits of such study have decreased segregation to the point where the variations in properties due to such effects have become unimportant.

The improvement in the quality of fabricating ingots with the consequent elimination of foreign inclusions and laminations and the reduction of blisters, slivers and similar metallurgical defects to an insignificant total, has come about as the result of persistent research to determine the best manufacturing practices. In many cases, these objectives could be reached only by the development of special equipment and special processes.

Because of the mechanism of the structural changes occurring during the solution heat treatment of aluminum alloys (readily appreciated by metallurgists), the final characteristics of the product are dependent upon the temperature to which it is heated in the solution heat treatment. The necessity for accurate temperature control is thus apparent. Originally, furnace equipment having the desired temperature accuracy and uniformity was not available, and the results of using such equipment as was available were not only widely varying properties, but considerable spoilage as well. Here again, research and development by both the user and the producers of furnaces, resulted in the manufacture of furnaces, both salt bath and air, having the necessary temperature control. Such furnaces are readily available today.

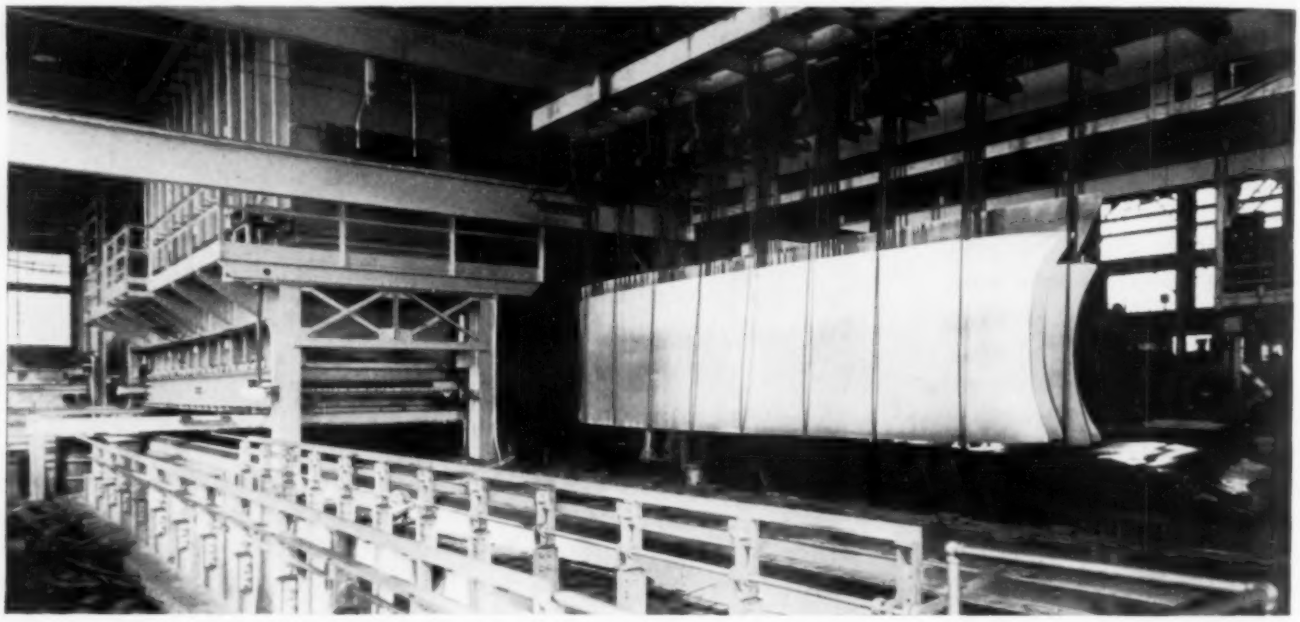
The improvements in quality and properties of 17S-T, touched upon previously, were the result of changes in manufacturing technique and procedure and did not involve composition changes, so that the alloy produced, let us say, in 1930, was substantially the same in chemistry as that produced in earlier years. It was realized by the producers that further improvements, particularly in tensile and yield strengths of the 17S composition, could be relatively minor if the easy forming and bending charac-

teristics of the material were to be maintained. Attention was, therefore, directed toward the development of a new alloy.

The task imposed was not an easy one, since the desired improvement in tensile properties could not be made at too great a sacrifice in those qualities of 17S upon which many of its uses were based; notable among these are good resistance to corrosion, excellent fabricating qualities, and spontaneous age hardening. It was apparent that the new material should not require radically different equipment in the users' plants than that already installed and used for working and heat treating 17S. A further important requirement was that the alloy, in the heat treated condition, should have a lower electrolytic solution potential than pure aluminum so that the "Alclad" products of the alloy would have the same excellent resistance to corrosion as does Alclad 17S-T. (Alclad 17S-T sheet is well known as material which is composed of a 17S core covered on either side with a thin layer of pure aluminum. The pure aluminum coating itself is exceedingly resistant to corrosion, and thus blankets and protects the underlying alloy core, but in addition it protects exposed areas of the core at sheared edges against corrosion attack by sacrificial action, since its electrolytic solution potential is higher than that of the alloy core.)

The requirements just enumerated indicated that the new alloy should have the same general constitution as 17S-T, that is, that the probable principal alloying elements should be copper, magnesium, and manganese. Research in this field resulted in the development and marketing, in 1931, of the new alloy 24S, after exhaustive fabricating, mechanical, and corrosion tests. Typical composition of 17S is 4% copper, 0.5% manganese and 0.5% magnesium; of 24S is 4.2% copper, 0.5% manganese and 1.5% magnesium.

It has since met with marked favor in the aircraft industry, as is attested by the fact that, since its introduction in 1931, the proportion of 24S to 17S consumed by it has increased annually, so that today the major proportion of strong alloy sheet, tubing, and extruded shapes used in the construction of aircraft is made from the 24S composition.



Plates up to 132 In. Wide by 35 Ft. Long Are Heat Treated in This Equipment. Racked up on edge they are lifted into elevated furnace in left rearground. Heating is by electrical resistor elements and forced circulation of atmosphere. To quench, the bottom slab of furnace rolls aside and plates are lowered into narrow quenching tank beneath, then slid to right under craneway for removal

The tensile properties, typical and minimum for specification purposes, are given on page 43. It will be noted that the minimum value for yield strength in sheet is 25% higher than that of 17S-T. This increase in yield strength is of particular interest.

In general, this alloy is handled similarly to 17S. In the annealed condition, its forming and bending characteristics are practically the same as those of annealed 17S. In the heat

treated condition (24S-T), the alloy requires more generous radii than does 17S-T. Like 17S, the alloy is definitely more workable immediately after heat treatment than in the aged condition; it is not, however, as workable as 17S in the same condition, and also hardens at a more rapid rate than does 17S, so that a shorter time interval after heat treatment is allowable for forming. For example, many rather severe forming operations may be performed on 17S-T within two hours following heat treatment, whereas on 24S-T the time limit for similar types of forming may be as short as one hour. Experience has indicated that, for the same type of forming, a greater proportion of 24S must be formed from the annealed temper, and then heat treated, than is the case with 17S.

The nominal temperature for heat treating 17S is 940° F. Because the constitution of 24S is somewhat different from that of 17S, a slightly lower nominal temperature, namely 920° F., is required. It is necessary that the maximum temperature be maintained below 930° F.

As is well known, the maximum resistance of 17S-T to corrosion is obtained by quenching the material in cold water with minimum delay in transfer from heating to quenching medium. This same principle holds for 24S.

It has been mentioned that Alclad 24S sheet, namely alloy with a thin coating of pure aluminum on either surface to form a product extremely resistant to corrosive influences, is available. The mechanical properties of this material are also given in the table. It is of interest that both Alclad 17S and 24S are meeting with increasing favor in the aircraft industry, for the performance since the introduction of Alclad 17S sheet, eight years ago, has established their dependability. The general employment of Alclad 24S today for structural members and for covering (in which latter application the material is used with no paint coating whatever) constitutes ample proof of this statement.

The general substitution of 24S and Alclad 24S for 17S and Alclad 17S has gone forward steadily. This substitution has been so general only because the higher strengths of the new materials have proved to be of such advantage to the aircraft builders as to outweigh the obvious disadvantages resulting from the change from one material to another with somewhat different working characteristics.

Aging of Duralumin

By P. L. Teed
Metallurgist, Vickers (Aviation) Ltd.

Condensed from Journal, Institute of Metals, Vol. 58

DURING a three-year study of problems connected with duralumin, it was found that the rate of age hardening at air temperature and the hardness ultimately reached of freshly normalized specimens, quenched in cold water, from the same sheet of duralumin was not influenced by the application of stresses during the aging period of the order of 7000 psi., which would be well below the elastic limit of the freshly quenched alloy.

In the present brief paper is considered the influence of plastic deformation on age hardening of test pieces from the same 16-g. sheet of duralumin, which were normalized at 915° F. for 30 min. and cold-water quenched. Each specimen was normalized and quenched, and its hardness at once determined; then all the specimens, with a few exceptions, were stretched in a testing machine to give a *permanent* elongation, which was later determined. Directly after this deformation, the hardness of each test piece was again measured, a procedure which was repeated at different periods during subsequent storage at air temperature up to 250 hr. after deformation.

Plastic deformation immediately following normalizing and quenching produces:

(a) An instantaneous increase in hardness roughly proportional to the measure of deformation employed; for instance, the Vickers hardness (10-kg. load) was 74 immediately after quenching, and this rose 18 points to 92 after stretching 2.8% on 4 in., 32 points after stretching 8.5%, and 39 points after stretching 15.5%.

(b) A small amount of plastic deformation increases the rate of aging during subsequent storage at atmospheric temperature even more than a considerable amount of deformation. Thus a quenched specimen ages at the rate of 0.4 Vickers number per hr.; if the deformation is 1.0 to 3.0% this rate of hardening is 3.6 to 3.2 per hr.; if the deformation is 5.0 to 9.0% it is about 2.0 per hr., and if 10.0 to 16% it hardens at 1.4 to 1.2 per hr.

(c) The hardening of deformed specimens is virtually completed more rapidly than in the case of undeformed material, say 20 hr. instead of 70 hr. *(Continued on page 94)*

Notes by the Editor, with comment
by Wilson L. Sutton
Chief Engineer, Fleetwings, Inc.

Aluminum alloys vs. stainless steels for aircraft

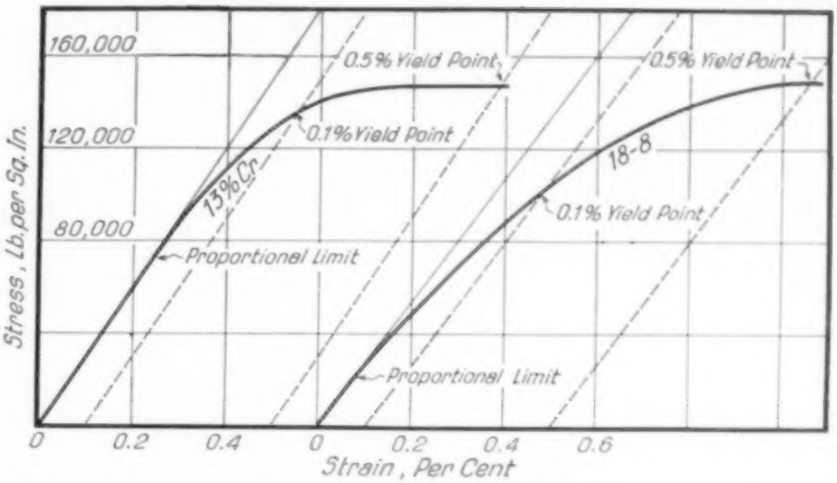
An important question relating to the use of stainless steels for light weight construction was brought up by W. L. Sutton's article in Metal Progress last June on "Stainless for Aircraft." Mr. Sutton is chief engineer for Fleetwings, Inc., a firm which has made many aircraft parts from cold-rolled 18-8 strip, and whose recent achievement is the all-stainless amphibian described on page 51. In view of the undoubted ability of this firm to construct in either steel or aluminum alloys, and of the fact that British aircraft freely utilize steel, either alloy or stainless, one is led to ask "Why is not stainless steel used more frequently in the construction of American airplanes?" It is thought that a correct answer to this question will have wider applications, for steel and the light alloys are sharply competing in the other transportation fields, namely high speed passenger trains and light weight bus and truck bodies.

Much study has been given to this problem by Goodyear-Zeppelin Corp. of Akron, Ohio, and the Editor is now enabled to present some of the findings. In the investigation of steels for possible use in airships, Goodyear-Zeppelin neglected the low alloy steels, in heat treated condition, because the gages for main members would have to be very light and could not be expected to withstand rust for an expected life of ten years. A non-rusting steel, then, was considered essential and studies were made on many variations of the austenitic chromium-nickel steels and the straight chromium steels. The latter are of importance, for the English utilize much steel covered by British Engineering Standard DTD54A, which is a chrome-nickel steel and DTD46A, which is a 12.5 to 14% chromium, 0.16 to 0.22% carbon steel. Each steel has a *minimum* proof strength of 145,000 psi. (Proof strength is defined as that stress at which the stress-strain curve departs by 0.1% of the gage length from the straight line of proportionality, as determined by an accurate extensometer.)

In the laboratory at Akron, autographic stress-strain curves were made with a specially developed extensometer, magnifying the strains by any desired factor up to 1000. It is noteworthy that in such testing some of the austenitic steels, heavily cold worked, would show a *proportional* limit as low as 3000 to 5000 psi.

Long-time tests included a stress-corrosion test. Sometimes peculiar corrosion failures were encountered, like the stress cracking shown in "The Book of Stainless Steels" (second edition, page 682). An experimental boom section of a 13% chromium steel failed without visible corrosion; it merely was in storage for three years after having been tested in compression, and is now a mass of small cracks.

The experimental shop at Goodyear-Zeppelin also conducted riveting, spot welding, punching, flanging and other formability tests. Boom sections of various design were then tested in compression and sometimes in axial fatigue. Booms made of 0.010 and 0.015-in. gages of the two steels above mentioned would



Typical Stress-Strain Diagrams for Heat Treated 13% Chromium Steel Containing 0.16% Carbon, and for Strain Hardened 18-8 Containing 0.12% Carbon. Note lower modulus (slope of line up to proportional limit), lower proportional limit, and lower 0.1% yield point of this 18-8

develop compressive strengths up to 130,000 psi. for the austenitic steels and up to 150,000 psi. for the straight chromium steels when tested as columns 12 in. long and about 1 in. diameter. Shorter lengths or heavier gages would develop a greater compressive strength.

These are quite high figures. Why, then, do aircraft engineers not use more stainless steel?

In the opinion of responsible engineers at Akron, as expressed to the Editor, there are three main reasons: First, the austenitic 18-8 steel, as compared to straight alloy steel or to the heat treated high chromium steels, gives disappointing values when tested *as structures* in which high elastic properties are essential (that is, high elastic limit and high modulus of elasticity). Second, the straight chromium steels, even though they possess desirable elastic properties, are difficult to spot welt and, when welded, lack ductility at the weld. Third, in many light structural applications and members, aluminum alloys are more efficient. This latter statement harmonizes with Mr. Sutton's article, wherein he says:

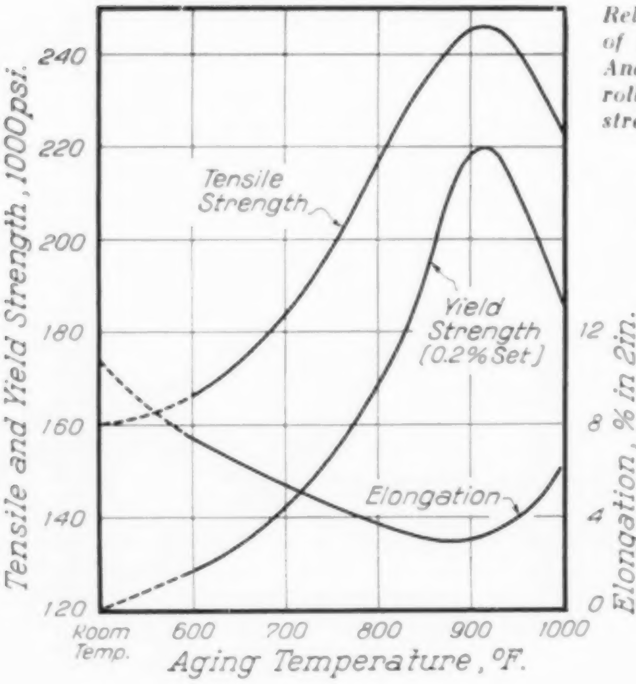
"The applied loads on the structure should be of such magnitude as to utilize a fairly heavy gage of stainless steel and by so doing minimize the local buckling and elastic failures. This premise points toward large airplanes as the best structures for stainless . . . In the small airplane as usually constructed, the selection of stainless steel would be dictated by the minimum gage obtainable from the rolling mill and the stability of the part made from these thin sheets rather than the stress requirements."

(Mr. Sutton's article compares 18-8 with super-duralumin, 24S-T, and the strength-weight ratios are even more favorable when the latter is cold rolled slightly and then heat treated, then known as 24S-RT. See Mr. Bossert's article on page 42.)

As Mr. Sutton says, "There is very little to choose between stainless and duralumin as far as strength of tension members of equivalent weight is concerned." However, the framework of rigid dirigibles is designed not on the ultimate tensile strength but on the yield strength, and the yield strength of 150,000 psi. for 18-8 quoted by Mr. Sutton in his article six months ago does not harmonize with experience at Goodyear-Zeppelin, which indicates that the minimum value would be at least 10,000 psi. lower. The U. S. Navy specification states that the yield strength is to be determined at a 0.2% set from a 25,000,000-psi. modulus line, rather than the 29,000,000-psi. modulus line commonly assumed for other alloy steels. If the structure must not yield locally, a direct comparison on the above basis will usually show a strong aluminum alloy such as 24S-RT to be superior to high tensile 18-8 with its rather indeterminate yield point. (By "direct comparison" the Goodyear engineers mean the fabrication of compression booms from the two alloys, making each the same weight, and testing them to destruction. Low compressive strengths in such booms and girders are often traced to local yielding at a point of stress concentration.)

Relative Formability

Formability, or ease of fabrication, is an important consideration, not readily evaluated by quantitative tests. Welding of thin 18-8 sheet by rapid spot resistance methods is held by Mr. Sutton to be a prime advantage over aluminum, which at present is almost universally riveted, although spot welding of the strong aluminum alloys is apparently now practicable, judging from work exhibited at the last Metal Congress. Aircraft girders call for a tremendous amount of forming and yet these are successfully made from the strong aluminum alloy 24S-RT, received in the fully hardened condition, without any special subsequent treat-



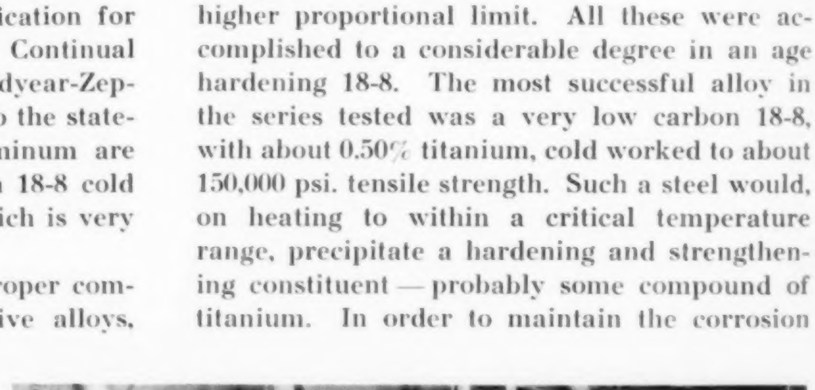
Relation of Aging Temperature and Tensile Properties of Stainless Steel Developed for Aircraft Structures. Analysis: 18% Cr, 8% Ni, 0.45% Ti, 0.06% C. Cold rolled to 0.028-in. sheet, having 160,000 psi. tensile strength as rolled. Aging time is 1 hr. in every case

ment. A comparison of the minimum bend requirements shows that there is little choice between 24S-T and 18-8. The first has a minimum bend diameter of 1½ to 3 thicknesses for 0.030-in. sheet, and the Navy specification for 18-8 calls for 2½ to 3 thicknesses. Continual contact with shop problems at Goodyear-Zeppelin Corp. leads men in that plant to the statement that the strong alloys of aluminum are considerably easier to fabricate than 18-8 cold worked to 180,000 to 200,000 psi., which is very "springy."

Leaving aside the question of proper commercial promotion of the competitive alloys, which is discussed in the editorial on page 33, such questions as the above may contain the answer to why stainless steel has not been used to a greater extent in aircraft. Summarizing the Goodyear-Zeppelin research in a broad way, it might be stated that for compression members the cold-worked 18-8 steels are not as suitable as either 17S-RT (minimum yield point 42,000 psi.), 24S-T (minimum yield point 40,000 psi.) and 24S-RT (minimum yield point 50,000 psi.). However, the straight chromium steels could be made to develop properties in compression members comparable to 24S-RT, but these alloys were not used because it was found that the fabricated member must be heat treated to relieve fabrication stresses (because of stress corrosion). Furthermore, the spot welding characteristics do not compare with 18-8, and riveting could not be considered because of the difficulty in drilling the hard steel, and because rivets could not be driven with properties comparable to the base metal.

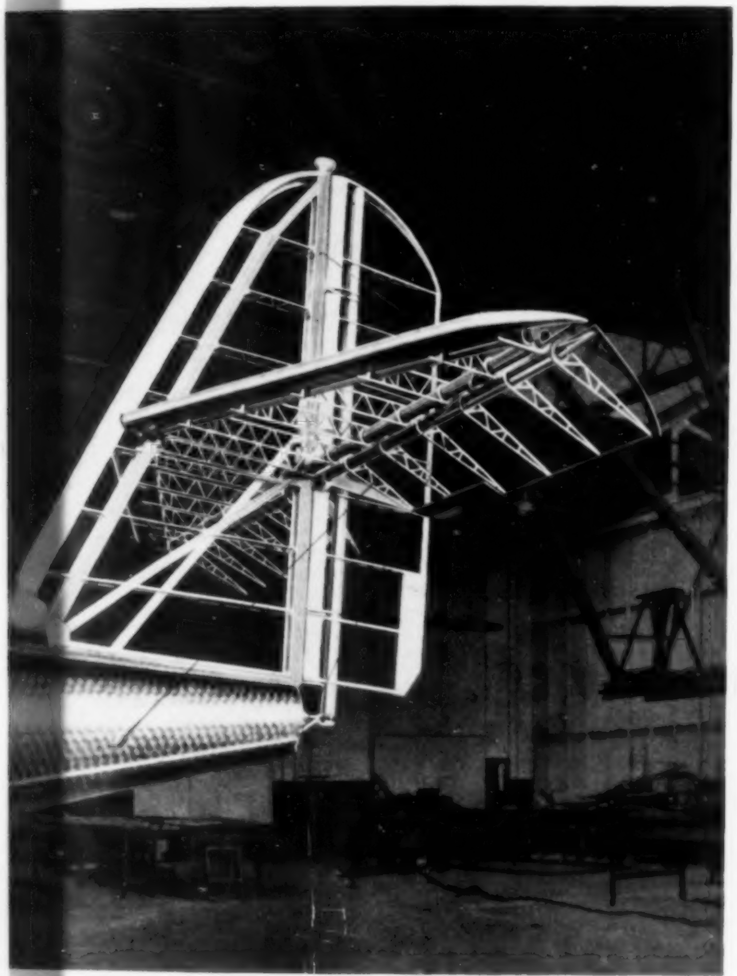
Knowing the requirements for the desirable aircraft steel, and having discovered the limitations of the existing steels, the next logical step was to attempt to develop a special steel for this type of service. This interesting development, which was made by Goodyear-Zeppelin Corp., resulted in a new alloy exclusively for aircraft; patent applications dating back to 1930 were made by Paul D. Ffield.

First it was attempted to raise the yield strength and elastic modulus of 18-8, and straighten out the stress-strain curve for a higher proportional limit. All these were accomplished to a considerable degree in an age hardening 18-8. The most successful alloy in the series tested was a very low carbon 18-8, with about 0.50% titanium, cold worked to about 150,000 psi. tensile strength. Such a steel would, on heating to within a critical temperature range, precipitate a hardening and strengthening constituent — probably some compound of titanium. In order to maintain the corrosion



Interior View of "Seabird," Showing Tubular Members of Main Structure, Frames, Stringers and Stressed Skin, All of Cold Worked 18-8 of Conventional Analysis. Joints made by shotwelding

resistance the titanium and carbon were kept low and the metal cold worked. (Without cold work about 3% titanium is necessary for the age hardening effect.) However, the necessary amount of cold working was moderate, and this is fortunate for it avoids expense in the steel mill and maintains good working properties in the steel, so that the structures can be fabricated in the softer or un-aged state, and then aged.



Unit Built Entirely of Stainless Steel; When Fabric Covered the ight Is 1.0 Lb. per Sq.Ft. All members are formed from flat strip

The optimum aging temperature (900 or 950° F.) was not high enough to cause distortion, and the scale formed at 950° is of a straw tint typical of temper colors, and is easily removed in hot nitric acid, which also passivates the structure.

Such an alloy develops the properties shown in the curve at top page 48. Yield strengths (0.2% set) as high as 240,000 psi. were actually obtained! The elastic modulus shows a recovery of about 2,000,000 on aging, from about 27,000,000 psi. to 29,000,000 psi., thus adding 6% to the stiffness.

Most important is the fact that the aging treatment, at about 900° F., will actually stress-relieve the structure. Fabrication stresses are known to lower, sometimes very materially, the strength of a structure, particularly in fatigue. Heat treatment to eliminate these stresses is therefore standard practice in certain codes — as, for instance, for fired pressure vessels. Tests made with these aging steels showed that stresses of yield point magnitude could be virtually eliminated in the aging treatment.

The significance of these experimental steels was that experimental booms were made which developed compressive strengths as high as 205,000 psi., thus demonstrating that stainless steel could be made, designed and fabricated into more efficient structures when a full understanding was had of its various properties.

Mr. Sutton's Comments

IN THE FOREGOING the statement is made that Goodyear-Zeppelin engineers have tested 18-8 stainless steel (heavily cold rolled) with proportional limit as low as 3000 to 5000 psi. The lowest proportional limit that we have record of is 14,000 psi., taken on *annealed* stainless steel with a Tuckerman optical strain gage. It is fully realized that this value is very difficult to check, since it depends on the testing procedure, the accuracy of the loading equipment, the extensometer, and the personal equation of the observer who must decide where is the point of tangency of a slightly bending curve. For that reason, testing engineers and designers have come to place more reliance on the yield strength. This has a fairly definite meaning for low carbon structural steel, but since there is no marked jog in the stress-strain curve of other alloys, an interpretation must be made by convention, such as "stress for 0.1% departure from the straight line of proportionality as projected upward."

What is the situation concerning the strong aluminum alloys?

The frame for the airship Macon was made of the alloy 24S-RT, but since I know of no maker of heavier-than-air craft using this particular material, I think the comparison should be made between 18-8 and Alclad 24S-T.

Alclad 24S-T is the only aluminum alloy that has even comparable corrosion resistance to stainless steel and physical properties high enough to compete with it. Furthermore, the

almost universal adoption of Alclad by commercial transport lines and the Army and Navy Air Services, forcibly demonstrates that the corrosion and painting difficulties of the aluminum alloys when bare are severe enough to compel the use of Alclad.

The physical properties of Alclad 24S-T we are relying upon are as follows:

Ultimate tensile strength	56,000 psi.
Yield strength	37,000 psi.
Proportional limit	27,000 psi.

To compare these on the strength-weight basis with cold-rolled 18-8, we can multiply them by the weight ratio (specific gravity of 18-8 or 7.93 divided by specific gravity of 24S-T or 2.77 which quotient is 2.86) and get the following results:

Ultimate strength	160,000 psi. (equivalent)
Yield strength	106,000 psi. (equivalent)
Proportional limit	77,000 psi. (equivalent)

The first two figures are clearly inferior to those we have been using with confidence in designing the 18-8 structures, namely ultimate strength of "full-hard" 18-8 of 185,000 psi., and minimum yield strength of 150,000 psi.

Yield Strength of 18-8

The matter of proportional limit will be discussed later; first let us consider yield strength.

Many tests on shipments of 18-8 received and fabricated by Fleetwings, Inc., do not check with the experience of the Goodyear-Zeppelin engineers, quoted in the foregoing pages, namely that the yield strength is more like 140,000 psi. when measured (as required by U. S. Navy specifications) from a modulus line of 25,000,000 psi. This value has always been exceeded in the steel we have received, and the usual yield strength for stainless steel with a modulus of 26,000,000 psi. is about 165,000 psi. To check these stress-strain curves against the practice used by Goodyear-Zeppelin testing engineers, we have replotted them against a base line, the slope of which is 29,000,000 rather than 26,000,000, and then measured the yield strength as a 0.2% deviation. This results in a yield strength of approximately 135,000 psi., which, compared with the 106,000 psi. (equivalent) for Alclad 24S-T, shows that 18-8 stainless is definitely superior as far as this important property is concerned.

It may be pointed out in passing that for certain types of structure the yield is the only criterion, and the effect of the modulus does not enter. An example is a cantilever wing or wing beam where the modulus of elasticity only affects the deflection of the wing tip. If the modulus of stainless steel were 26,000,000 rather than 29,000,000, the deflection would merely be somewhat greater, in the same ratio. The major cause of any failure would be inferior yield strength of the material — that is, a change from elastic deflection to plastic flow under the loads imposed. For a structure such as this it would be far better to have a comparatively low modulus and a relatively high yield strength.

To return now to the low proportional limit of commercial 18-8; as remarked above, the establishment of the true value of proportional limit depends greatly upon the accuracy with which the readings are made. Whereas we have had cold-rolled 18-8 stainless steel with a proportional limit as high as 100,000 psi., the average value is between 50,000 and 70,000 psi., and the minimum seldom drops below 40,000 psi. These figures are definitely inferior to the equivalent values for Alclad 24S-T, but they can be improved.

V. N. Krivobok, R. A. Lincoln and Robert Patterson, Jr., reported to the last ⊕ convention a series of tests made at the research department of Allegheny Steel Co., wherein 18-8's over a considerable range of analysis and cold reduction were studied as to their tensile and bending properties. (See Metal Progress, October 1936, page 243.) They used the "proof stress" as a criterion, defining it as the stress which when released results in a permanent set of no more than 0.0002 in. in a gage length of 2 in. (0.01% strain). This is the threshold where true elastic action no longer obtains, and in a purely practical sense may be taken as equivalent to the concept of the proportional limit for those alloys where the stress-strain curve is undoubtedly straight for a considerable distance.

Dr. Krivobok and his associates find that it is possible to obtain proof stress (proportional limit) of 150,000 with an ultimate tensile strength of 197,000 psi. This, however, results in a loss of elongation which would tend to make the forming operations too hard for ordinary shop practice. It has also been found feasible to obtain a proof stress (proportional limit) of slightly over 100,000 psi. with an ultimate tensile strength of 185,000 psi. and still have satisfactory elongation in the material (on the order of 9%). In my opinion this is clearly

superior to Alclad 24S-T with equivalent proportional limit of 77,000 psi.

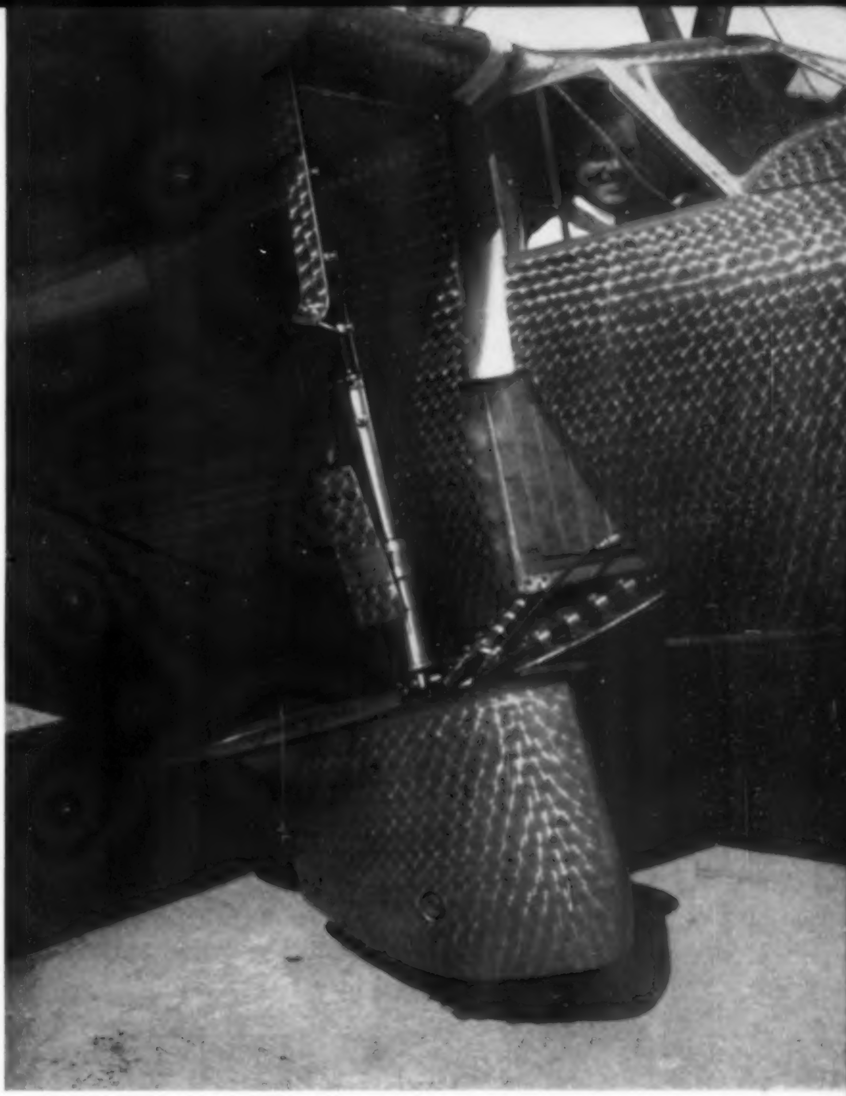
Of course there are far more considerations concerning the suitability of a material of construction than the existence of a high or low proportional limit. To sum up the entire matter it may be said that over a period of six years we have been able to utilize stainless steel for aircraft structures and satisfactorily predict its outcome under various loadings and conditions. I venture to assert that other firms now operating almost exclusively in aluminum alloys will have the same experience.

The Seabird

Considerable publicity was obtained in the popular press by an "all stainless" amphibian, recently constructed to designs of Carl de Ganahl, president of Fleetwings, Inc., and the writer. "All stainless" is not strictly true. The engine and its auxiliaries, of course, have a galaxy of special steels and non-ferrous alloys. The propeller is of duralumin. It being but a small ship, the wing, tail and control surfaces are of fabric. The cowling of the motor is of 52S aluminum alloy, spot welded, and the highly stressed parts of landing gear and engine support including the engine mount and struts are of chrome-molybdenum seamless steel tubing, oxy-acetylene welded and heat treated. The struts supporting the pontoons are also of this steel tubing, chromium plated. All stay wires are streamlined and made of 18-8 steel. There is also a rather unusual use of wood in the keel and the chines or edges of the hull, because it was impossible to determine the exact shape for optimum service, short of actual trial, when metal will replace them.

The hull was constructed entirely from stainless steel, the aft and forward portions being of semi-monocoque construction, while the cabin, or center portion, was fabricated from spot welded, thin wall tubing. Closed sections were used throughout the hull to attain high structural efficiency and do away with any susceptibility to local damage or handling.

Operations in assembling the hull reversed the usual procedure: The transverse frames were set up on a jig, the longitudinal stringers temporarily placed in position, the outer skin temporarily placed on the stringers and shotwelded to the stringers at a few isolated points. Then the entire unit consisting of the outer sheet and the stringers was removed from the jig, and the longitudinal stringers completely shotwelded to the skin in an automatic welding machine, taking approximately three days. These units were made up in panels approximately 4 ft. wide, and when complete were replaced on the transverse frames and welded into place, thereby completing the assembly.



Steel Skin of "Seabird" Has Been Burnished by Blunt Nosed Tool, Thus Breaking up Disturbing Reflections. Shrouds on landing wheels become rudimentary wings just under pilot's window when gear is retracted

The outer sheets were of double curvature or "crowned," and hence originally were made in small widths and seam welded. This was done over a male form on which was placed a flat piece of copper strip at the junction line, to act as the return main for welding current. The narrow strips of 18-8 were then strapped in place and poke welded at approximately 6-in. intervals along the lap. Sheets, thus joined together, were then held together well enough to allow them to be seam welded.

Tubular members in the center portion of the hull were made from flat strip, rolled on the brake, and shotwelded together. It was thus possible to obtain a thinner wall than is available in commercial seamless tubing. Joints

between the tubular members were made by shotwelded gussets and plates, great care being exercised in the design to obtain outside welding for ease in fabrication. Some details are photographed on page 48.

The tail unit illustrated on page 49 was built entirely of stainless steel, its spars and ribs being made from flat strip stock. The unit weight of this tail group was slightly less than 1 lb. per sq.ft., covered, and it is remarkably rigid under static test.

Wings (except for fabric cover) were fabricated entirely from stainless steel. Wing ribs were made of stainless steel panels shotwelded together, the compression struts were contour ribs built up of drawn stainless steel sections and braced with stainless steel drag wires. The spars were fabricated box sections, externally supported by stainless steel streamlined wires. Supported between the wing spars were two 26-gal. fuel tanks of a rather unique design — very flat, but notwithstanding this poor shape, dictated by the size of the wing, had a unit weight of only 0.6 lb. per gal. of capacity.

Wing tip floats were made entirely of stainless steel, seam welded to secure watertightness. Although the weight of these floats was remarkably low (17 lb., including struts and wire bracing), no failures occurred during tests in very rough water.

Ailerons are of stainless steel ribs shotwelded to a seamless steel torque tube. This torque tube was so positioned in the nose of the aileron that static balance was achieved without the use of lead. Flaps were formed by automatically shotwelding corrugated to flat sheet, both being 0.006 in. thick. These have stood up under static test without undue deformation or permanent set.

The landing gear was built entirely of acetylene welded, X-4130 chrome-molybdenum steel except for the shock absorber strut and the brake bands. The shock absorber strut and the brake bands were made from stainless steel by the Bendix Co., in an effort to lessen trouble incurred by salt water corrosion.

This airplane, weighing 2286 lb. empty, is in the class where many of the member sizes are dictated by the minimum size of the sheet available and the difficulties in handling this thin material. However, the ratio of weight empty to gross load of 33% is comparable to that obtained in many present-day land planes. If the landing gear were to be left off and the Seabird were designed as a flying boat rather than an amphibian, the ratio of useful load to gross load would be approximately 40%.

Since this ship was largely designed by the minimum size and thickness of material attainable, it is logical to infer that the large, heavily loaded airplane could be constructed with an even better structural efficiency.

Influence of Vanadium on Ni-Cr and Ni-Cr-Mo Steels

By H. H. Abram

Research Dept., Woolwich Arsenal

Condensed from paper for September 1936 meeting of British Iron & Steel Institute

A PAPER in *Journal* of the Iron and Steel Institute, 1934, No. II, showed that in carbon steels and nickel-chromium steels vanadium induces a mild hardening during the tempering operation which tends to counteract the softening normally produced by a progressive rise in the tempering temperature from 925 to 1150° F. The deleterious effect on the impact figure which accompanies the greater tensile strength produced by such "temper hardening" was considerably less in nickel-chromium-vanadium steels than in carbon-vanadium steels. The present paper deals with the influence on the mechanical properties of additions of vanadium to nickel-chromium and nickel-chromium-molybdenum steels.

Two series of steels were studied, one containing about 0.30% carbon, 0.20% manganese, 2.0% nickel, 1.0% chromium, no molybdenum, and vanadium ranging from none to 0.46%. The other series contained about 0.30% carbon, 0.65% manganese, 2.6% nickel, 0.70% chromium, 0.65% molybdenum, and variable vanadium.

In preliminary studies to find the best quenching temperature it was found that raising the hardening temperature from 1560 to 1740° F. reduced the tensile strength of the hardened and tempered steels that were free from vanadium, but progressively increased the strength of the steels containing vanadium as the vanadium content rose. These changes in the tensile strength were in general accompanied by the usual corresponding changes in the yield point, elonga- *(Continued on page 92)*

By C. F. Olmstead
Sales Engineer
Mahr Manufacturing Co.
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Heat treating equipment at Consolidated Aircraft Corp.

CONSOLIDATED AIRCRAFT CORP., which since 1923 had operated in Buffalo, N. Y., moved into new quarters at Lindbergh Field, San Diego, Cal., about 18 months ago. Production started a few months later on a contract for 60 long-range (24-hr.) patrol flying boats for the U. S. Navy. This taxed the facilities of the original factory building, some 300x900 ft. in area, and when another contract for 50 all-metal pursuit planes for the U. S. Army was secured, plant additions were rushed through almost doubling the floor space.

Since heat treating is a very important operation in the manufacture of these duralumin planes a centrally located area is set aside in the main plant, and the furnaces grouped close enough to simplify handling and supervision. The four larger units were furnished by the Mahr Mfg. Co., and consist of a gas fired salt bath for duralumin, a small gas fired, car bottom furnace for engine mounts, a gas fired furnace for heat treating tools and miscellaneous small parts, and an electric furnace intended primarily for tempering these same small parts but powered so that it can be used at heat treating temperatures if desired.

A small cyanide pot furnace was furnished by Knapp Furnace Co. for case hardening small tools and parts.

By far the largest amount of material treated is duralumin, and this is done in a liquid bath containing 22,000 lb. of sodium nitrate and potassium nitrate, half and half. The container is of welded boiler plate ⅞ in. thick, 38 in. wide by 15 ft. 8 in. long by 50 in. deep. It sets in a heating chamber lined with 4½ in. firebrick and 2½ in. insulating brick. Gas burners fire one from each end into ducts along the sides and under the pot. Tile over these ducts are spaced so as to regulate the size of openings according to their distance from the burner end of the furnace and compensate for velocity and pressure losses; in this way the heat distribution is uniform, end to end and side to side. Utilizing two burners instead of a larger number simplifies adjustment and control.

Covers are provided in three sections, pivoted at one side of the furnace and counterweighted. These reduce radiation and stand-by losses. When heating short sections, only one-third of the bath needs to be uncovered for charging and removing stock.

Natural gas is regulated for delivery to the furnace at a uniform pressure of about 6 in. water column. It passes through a "zero governor proportionater" of the diaphragm type interconnected with the air supply line to the burner in such a manner that when air flows, pressure on the diaphragm opens the gas valve and allows gas to flow in a proportional amount for correct combustion conditions.

Air supply is furnished at 12 oz. pressure by a 1-hp. motor driven blower mounted on the floor near the rear center of the furnace, the air pipe branching to the burners at the ends

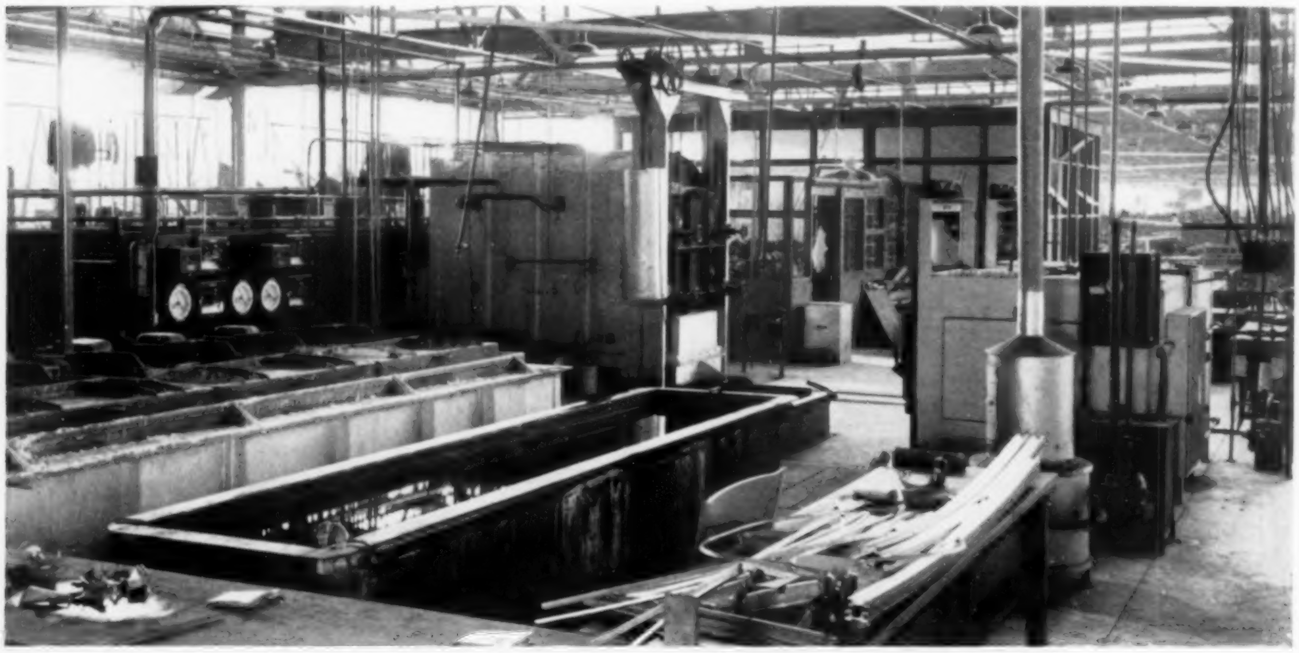
of the furnace. The air flow is automatically controlled by a valve linked to a small two-position motor reducer, electrically connected to the pyrometer in such a way that when the temperature is slightly above the desired setting, the air valve closes, and the gas valve closes far enough to leave only a pilot flame. When temperature drops a couple of degrees below the desired setting, the air turns on, the gas comes on, and thereby the temperature is maintained within very close limits.

Each burner is controlled separately, and it has been found best to have one control thermocouple in the liquid bath and the other in the combustion chamber, setting both nearly together so as to minimize lag (over-shooting and under-shooting of temperatures) caused by the large volume of liquid in the bath, the thickness of plate in the pot, and the storage of heat in the brickwork.

There is also a recording pyrometer which continuously registers the temperatures at four points along the length of the bath. The temperature throughout is so uniform that the four records make one continuous straight line on the chart. This furnace operates mostly in the neighborhood of 930° F.

A car bottom furnace is also provided for heating alloy steel engine mounts, which are tubular frameworks attached to the front of the plane. An engine mount is made of the highest grade of alloy steel tubing, welded into the proper structure. To prevent sagging and distortion while being heated to nearly 2000° F., it is held in a fixture supporting overhanging points and important center dimensions. The furnace is large enough to take two of the largest assemblies; the effective heating space is 4 ft. wide by 8 ft. long on the car, and the door opens 4 ft. high above the car top.

This furnace is designed to heat a 1000-lb. charge to 2000° F. in 2 hr., and to hold it within close limits of temperature uniformity. Burner equipment is provided for operating within a wide range of temperatures, 500 to 2000° F., with the same uniformity. These burners are of the "premix" type; that is, air from a 3-hp., 12-oz. blower passes through gas proportioning valves, and by an inspirating action in these, the gas is drawn in at the correct volume ratio for burning completely. The air flow is controlled in the same way as in the salt bath furnace, namely by a motor-operated air valve, interconnected electrically with a pyrometer controller.



Aluminum Alloys, Cast, Rolled and Forged — Alloy Steel Weldings, Forgings and Machined Parts — Tools and Fixtures — All Come to This Compact and Centrally Located Department for Heat Treating

This furnace also has, in addition to the recording pyrometer controller, a pyrometer which continuously registers temperatures from any desired four points in the furnace chamber.

The refractories forming the bottom of the furnace are laid on a flat steel deck plate of a substantial car, whose wheels have roller bear-

ings. Underneath the center of the car, full length, is a rack which engages a pinion; the latter is supported in bearings fastened to the foundation at the front of the furnace. A motor-driven gear reducer turns the shaft on which the pinion is mounted, and by push button control the operator can run the car into and out of the furnace, either hot or cold, at the rate of about 40 ft. per min.

The customary procedure is to withdraw the car from the furnace and set the engine mount, already braced, on its top in the best position to prevent sagging at heat treating temperatures. The car is then moved into the furnace and the door lowered. When the mounts reach temperature uniformly, they are withdrawn and quenched by compressed air jets directed on them from both sides.

Air is prevented from entering the furnace through the clearance space between furnace walls and car edge by a trough seal on the car edges filled with sand, into which fits a metal flange fastened to the wall of the furnace. The rear of the car slides up under a brick ledge; and wet clay or asbestos wedges it up tight on the front of the car, thus completing the seal.

Use of Insulating Refractories

The furnace is lined with light weight insulating refractories which reduce heat storage and retard conduction through the walls, thereby making a unit which heats quickly and economically.

In addition to the engine mounts and the aluminum alloys there are many dies, tools, and miscellaneous parts to carburize and heat treat. Due to the variety of materials of varying analysis and physical property requirements, this furnace is called upon to change temperature frequently. Light weight refractories are particularly advantageous for such quick changes, made by simply turning the dial on the pyrometer.

Burners of the "premix" type already described are located above the hearth as well as below it. Air is furnished by an individual 1-hp., 12-oz. blower. There is also a motor-operated air valve, a pyrometer controller, and a separate recording pyrometer for making a continuous chart of temperatures at two points in the furnace.

This furnace, 24 in. wide, 18 in. high and 48 in. long, was designed for operating at temperatures of 1000 to 2000° F. and heating charges to 600 lb. During the day it heat treats practically everything except the engine mounts and large annealing or carburizing charges. At night these carburizing and annealing charges are run.

When tempering material hardened from the gas fired furnace described just above, there is an even wider range of load, time, temperature and uniformity requirements, and an electric furnace was found to be more suitable than a fuel fired one. The electric furnace installed has the same working dimensions as the gas fired furnace. It operates mostly in the tempering range 500 to 1100° F., but it can also be run up to 1800° F. and used for heat treating if desired.

Small, highly refractory holders are attached to the inside surface of the insulating firebrick lining by alloy bolts, the heads of which recess into the middle of the holders, the threaded end extending through holes in the outside metal casing and held there by spring washer and a nut. The hearth plate is of nickel-chromium heat resisting alloy, and the lining is all light weight refractories for quick variation in temperature.

The resistors themselves are nickel-chromium ribbon and rest in the slot formed by the above described holders. Terminals extend through the back wall, suitably insulated from each other and the casing, and are connected into a three-phase balanced circuit by external wiring and covered with a perforated, ventilated housing. There are 12 complete elements in all, four on each side and four on the bottom, making a total connected load of about 60 kw.

A dry type auto transformer reduces the 440-volt supply line to 220 volts maximum on the elements. Also a tap-changing transformer is in the circuit which may be set manually to reduce the input to 25%, 50%, and 75% of its full rating.

The pyrometers and other instruments for all of these furnaces are mounted on one panel easily visible and accessible to the operators. As shown in the view the furnaces are closely grouped for convenience of handling materials.

Metal treated in all of these furnaces goes through an exceptionally rigid inspection by Consolidated employees and by government inspectors. The resulting physical properties are uniformly well above the requirements, and rejections practically unknown. This means much towards long service under severe operating conditions and the safeguarding of life.

By Gilbert E. Doan
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Industrial uses of invisible rays

THE UNIVERSE around us, even to the remotest stars, is alive with vibrating radiations, which we speak of according to their wave length — cosmic rays, wireless waves, infra-red radiation, visible light, ultra-violet light, X-rays, and gamma rays — all as shown on the chart, page 61. Of this vast field only a small region affects the retina of our eyes or, as we say, is visible to us. The visible spectrum contains all of the colors of the rainbow, so let us call the rest of this vast field of radiations the Invisible Rainbow, for it is really just that. All the rays shown on the chart, with the exception of the sound waves (which require matter to transmit them) travel through empty space with the same velocity, the velocity of ordinary light, about 186,000 miles per sec. It is the *new* uses of these radiations that will occupy this article, adapted from a talk given before many ⊕ chapters.

Extending from wave lengths of some miles, as in the longer radio waves at the left of the chart, to wave lengths of a few millionth parts of an inch in the gamma rays and cosmic rays at the right, there is a broad range of electromagnetic waves, of which only one octave is visible radiation and produces upon our eyes the sensation of light; namely, that octave comprising wave lengths from 30,000 to the inch down to 60,000 to the inch, as shown on the enlarged part of the chart. Outside this range of about 1/30,000 of an inch we are blind! Yet the realm of unseen rays is vast as compared with the visible — sixty octaves or more of invisible rays to one octave visible.

It may be well to pause here to appreciate more fully the significance of this chart. It makes clear to us that all of the wave-lengths from the very shortest cosmic rays and gamma rays a billionth of an inch long at the right of the chart down through the range of visible light to the longest radio waves and electric waves several miles long at the left end, are members of the same family and are as much like each other in nature, in fact much more so, than the little bear and the big bear in the fairy tale, or like the ripples in a tea cup and the waves of the open ocean; that is, they differ only in size. All the radiations, as I should like you to remember, are propagated with the *same* velocity as visible light and, like light, these other rays can exhibit refraction, polarization, and interference. For example, interference phenomena can be obtained with the Hertzian waves used in wireless telegraphy by reflection of these waves from the so-called Kenelly-Heaviside layer in the heavens above us, just as with visible light at a diffraction grating or with X-rays from a crystal lattice.

Nature of Radiation

If we ask what is the nature of radiation, we find ourselves in the forefront of modern physics. Roentgen, who discovered the X-rays, Becquerel, the gamma rays, and Hertz, who discovered the wireless waves, did not even suspect that their radiations were of the same nature as visible light. But today we know that all these rays are a part of our invisible rainbow.

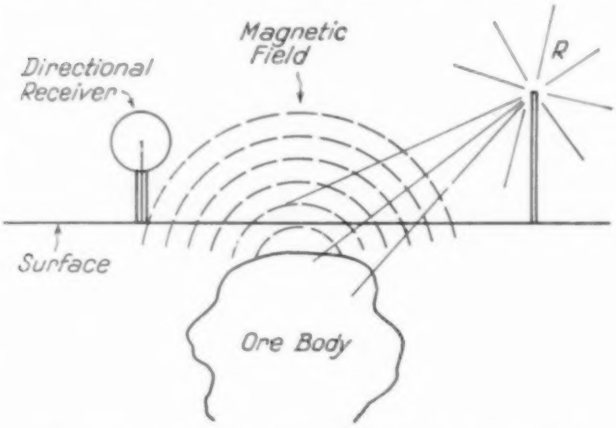
Until very recently there was a sharp distinction between radiant *energy* and *matter* but this seemingly fundamental distinction bids

fair to disappear. During the last few years a promising path seems to have been found in the theory of wave mechanics initiated by deBroglie and Schrodinger. The distinction between matter and radiation becomes shadowy, for an electron (the unit of matter) is believed to be a certain "singularity" in a group of waves. While waves possess certain of the properties of particles, likewise particles possess many wave properties.

New Fundamental Concepts

The great achievement of the last quarter of the 19th century was the explanation of matter in terms of electric charges. The next period bids fair to be one in which electric charges and radiation will be explained on a common basis, as different manifestations of something more fundamental, but at present less definite, foreshadowed by the new wave mechanics.

About the modes of generation of these radiations, it may be said merely that there is a range of generators of widely different sizes passing from the coils of wire and condensers with which the longest electric waves are generated down through those oscillators consisting of two minute metal filings, then on down to vibrating molecules which produce visible light, to changes in the orbital electrons of an atom producing X-rays, and finally to changes in the nucleus of an atom itself resulting in gamma rays and possibly the cosmic rays.



Numerous Important Ore Discoveries Have Been Made With the Help of Long Electric Waves. Waves from coil antenna R induce electric currents in ore body, which in turn modify the earth's magnetic field and these modifications are studied by portable directional receivers as indicated

But we wish to discuss new uses of these radiations in modern engineering, rather than their magnitudes, modes of generation, and ultimate nature.

Long Electric Waves — As all metallurgists know, the long electric waves at the bottom of the spectrum are used in the operation of the high frequency induction furnace for melting metal. "High" frequency is something of a misnomer, for while "high" in comparison with ordinary electric circuits, they are among the lowest in the electromagnetic spectrum. Waves from 10 to 100 miles in length, the giants of the family (of frequency 3000 to 30,000 cycles per sec.) originate in a solenoid or cylindrical coil as primary, and are intercepted before they go very far by the metal to be melted, which is in the crucible placed inside the solenoid. The absorption of these waves in the metal sets up secondary currents, and these currents heat the metal in the crucible as hot as is desired in a very short time and without contact with air. But the coil which is carrying the current remains cold. The early development of this useful metallurgical tool by E. F. Northrup was fully described in METAL PROGRESS last January.

A Scientific Divining Rod

Another use of these long electric waves is in prospecting for metal bearing ores. As shown in the sketch, electromagnetic waves about 25 miles long are sent downward from a coil antenna *R* on the surface of the earth. If these waves enter an ore body, they induce in it a current, much as they do in the metal in the crucible of the induction furnace just described. The ore body, now carrying a current, sets up a magnetic field, which passes readily through the rocks and earth to the surface. The chief operation is in locating the conductor (that is, the ore body) by determining upon the surface of the earth the direction from which this magnetic field comes.

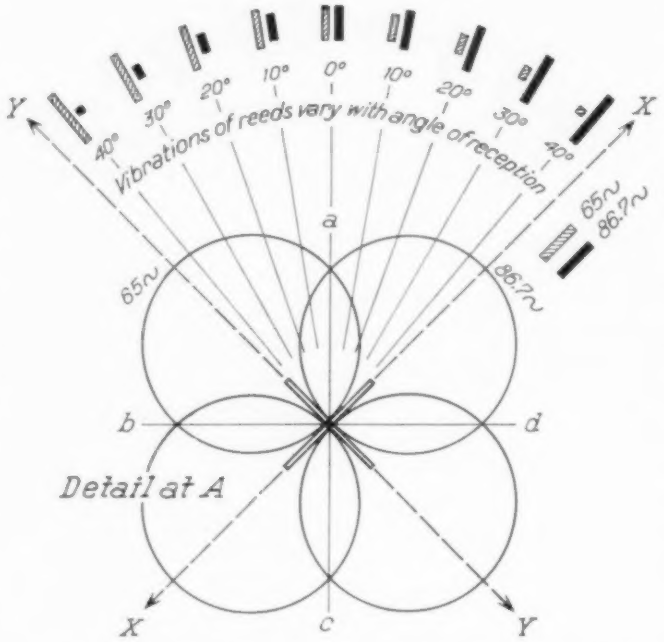
Heat Waves — Waves 30 m. (about 100 ft.) long, from a modified type of radio tube, if intercepted by the human body, cause the body temperature to rise and thus produce an artificial fever which seems to kill the germs of asthma, arthritis, or paresis. The radio fever is less injurious than the malarial variety. These discoveries about heat rays have come from the laboratories of the General Electric Co. The variety of the uses of the invisible rainbow is already amazing, is it not? See now — we have examined only three wave-lengths and yet we have gotten into the melting of steel,

prospecting for ore, and curing disease! What may we not discover next!

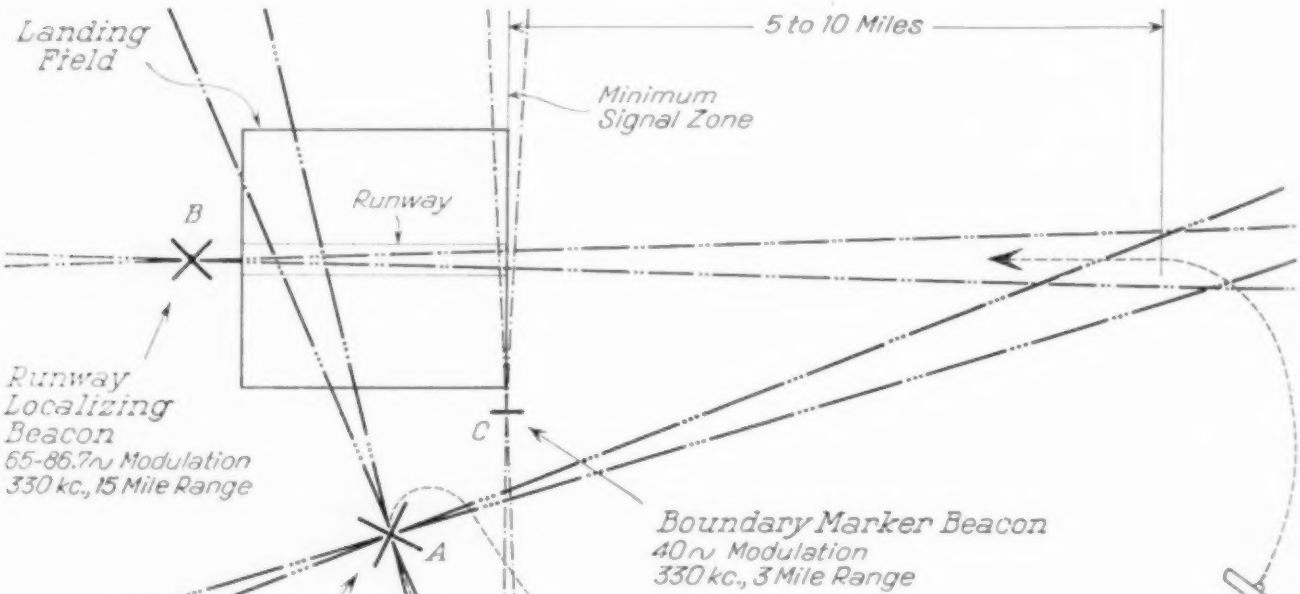
Radio Waves — The next range on the chart includes the so-called radio waves of lengths from 6 in. to 20 miles. New though they are, they are commonplace servants of mankind. One of the latest uses of radio or wireless waves is in providing guidance for airplanes along a flying route above the clouds, and for landing in a fog. Guidance for the flier is provided in all three space directions — laterally, vertically, and longitudinally — by radio waves.

Lateral guidance to keep the fliers on the course is provided by two directive beams of rays sent out from two pairs of coil antennae, each pair crossed at 90° as illustrated in the sketch in the center of this page. Interference in the waves from each of the crossed antennae results in two directional beams, X-X and Y-Y of different wave length, between 3 and 4 m. These two beams cause two reeds to vibrate on the pilot's control board. When an airplane flies along a line exactly equidistant from the two beams of radio waves (as on course *ac* or *bd*) the two reeds vibrate so that they appear of equal length and the pilot knows that he is on the course, as shown by the 0° position in the sketch, detail at *A*. If the airplane gets off this line, it receives a stronger signal from one beam than the other and the pilot swings it over until the indications are equal.

Vertical guidance during landing is sup-



Short Wireless Waves for Radio Beacons and Blind Landings. Principle of beacon is shown above. Waves of two lengths emanate from crossed coils and cause (through interference) directional beams in directions X-X and Y-Y. An instrument in the ship has two reeds, whose vibrations to the respective beams determine the azimuth of the ship. Plan, below, shows how combination of long range radio beacon and short range beacon can be used to locate an invisible landing field



plied by a 3-m. beam at 8° declination to horizontal sent out from a station (not shown in the sketch) near the runway localizing beacon. Beam *C* prevents him from overshooting the field longitudinally, as shown on the plan view showing an approaching pilot. Coming from the lower left, he keeps midway between the two beams, overshoots station *A*, turns back and glides down the landing beam *B* until he passes *C*, indicating he is over the field proper, all without seeing the ground beneath him. The Bureau of Standards has sponsored these developments to aid commercial aviation.

Infra-Red Waves — Now let us see where we are on the chart of page 61. Beside the heat waves in the electromagnetic spectrum are the infra-red rays of length about 0.001 in. These waves, like the longer ones we have been discussing, do not affect the retina of the eye so as to give the sensation of light. But they have a very important ability to penetrate clouds and fog. So when a sea captain wishes to take his bearings at noon on a cloudy day, when the sun is invisible, he points a reflector, somewhat like an automobile headlight, through the rain, fog, and clouds toward the zenith, and rotates it until in a certain direction the sensitive thermocouple inside the reflector gives a maximum reading. That is the direction of the sun, and from this position and from his charts he calculates the latitude and longitude of the ship. The infra-red rays from the sun have passed through the clouds and rain and, after striking the reflector, are concentrated on a bismuth-silver thermocouple which registers a maximum on the attached galvanometer when the reflector is pointed directly at the sun. The infra-red sextant is said to be so sensitive that it will record the heat rays coming from a man's face a mile away.

This transparency of clouds and haze to the infra-red rays is now used also to photograph cities which are hidden by clouds or haze. The city of Washington has been photographed from the air while covered with a blanket of fog and smoke so dense that the city was invisible to the aviator who took the picture. New York viewed from a skyscraper looks like a clean city! Mountains at a distance are frequently hidden by atmospheric haze, which produces what artists call "aerial perspective." Considerable publicity has recently been given to a picture taken 23,000 ft. above Salinas in southern California which shows Mt. Shasta dimly past the horizon, 331 miles away. At the time he

Ultra-Violet Light, 5000 Diameters Magnification, and Exacting Technique, Bring Out Laminated Structure in Martensite "Needle" in Hardened Steel. Photo by Lucas

took the picture, the aviator could not see the mountain at all, even with the strongest telescope. Part of the region between the camera and the mountain is hidden by the curvature of the earth's surface but the mountain sticks up above the horizon. Galileo would not have had to recant saying the earth is round if he had shown this photo to his prosecutors.

Special Eastman films, made sensitive to infra-red rays by the presence of a chemical called cyanine, are used for this purpose. Such films are also used by astronomers in photographing stars and eclipses. Since these infra-red rays are invisible, it is possible, of course, to take photographs in the dark, that is, in total darkness as far as the eye can perceive. I have seen a photograph of a plaster bust, "illuminated" by two flat irons at ordinary ironing temperatures, the entire room being "pitch dark." The flat irons give off infra-red waves which affect the film but not the human eye; these films can actually see a part of our invisible rainbow.

Ultra-Violet Light — When the wave length is shorter than 1/60,000 in. it again loses the

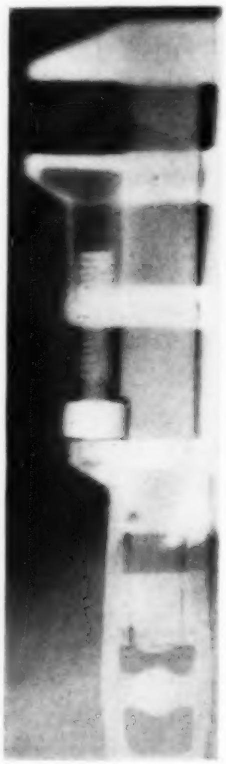
ability to produce the sensation of light on the retina of the eye. Such ultra-violet light does, however, still affect the photographic plate. These plates are more sensitive than our eyes.

Ultra-violet waves coming from an object under the lens of a special microscope, because of their shorter wave length, give greater fineness of detail called "resolution" to the image seen by the observer, than does visible light. Such a photograph, page 59, shows the internal structure of a heat treated carbon steel at a magnification of 5250 diameters. Note the clear resolution of the finer stripes, six-millionths of an inch apart. Nearly 3000 of these stripes could be laid side by side on the cross section of a human hair! Under visible light the entire structure would be a blur, with no stripes visible. The Bell Telephone Co. research laboratory also uses this wave length to measure distances to one-millionth of an inch.

In the detection of forgeries or erasures ultra-violet light is useful too. Many an erasure, when it appears perfect to the eye, shows the original inscription plainly, because of fluorescence in the ultra-violet. Other new uses of ultra-violet, as the treatment of foods, artificial sunshine, the acceleration of chemical reactions, killing of bacteria, are perhaps well known. Apparently a narrow band of short waves just beyond the rainbow marks the spot where health, the pot of gold, lies buried.

X-Rays — X-rays, length about one-millionth of an inch, like ultra-violet rays, also are invisible to the eye — but they also blacken the photographic plate. But in addition, as you all know, X-rays penetrate so-called opaque "solid" matter so that when a tooth is decayed or a bone broken we can "see through" the solid material which hides the cavity or fracture. The treatment of cancer by X-rays is also familiar.

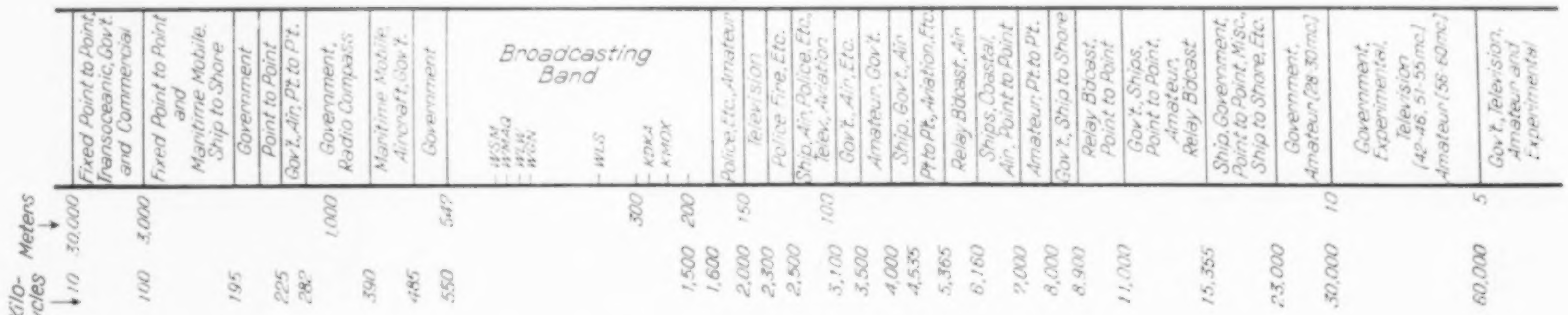
Shadows Through a Monkey Wrench. The first gamma radiograph made by Mehl, Doan and Barrett



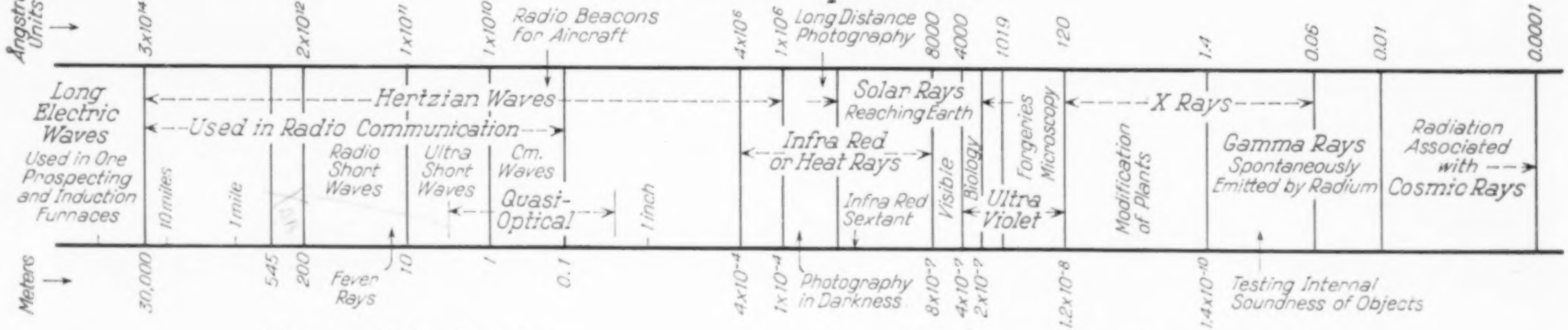
While the new uses of invisible rays which I have described thus far, excepting the production of artificial fever, are in the field of the mechanic arts, that is, in the field of engineering, I should like to mention here, briefly, a new use in the field of biology. Recently at the laboratories of the General Electric Co., grapefruit seeds were exposed to X-rays for two minutes before planting. The result is that the seedlings bore a bud within five weeks after planting instead of 5 or 10 years later, as normal plants do. Similarly, the seeds from tobacco buds yield *(Continued on page 98)*

Since Radium Emits Gamma Rays of Equal Intensity in All Directions, Films Can Be Placed All Around a Large Siege Gun Slide and Exposed to Emanation Later Placed in Funnel at Center

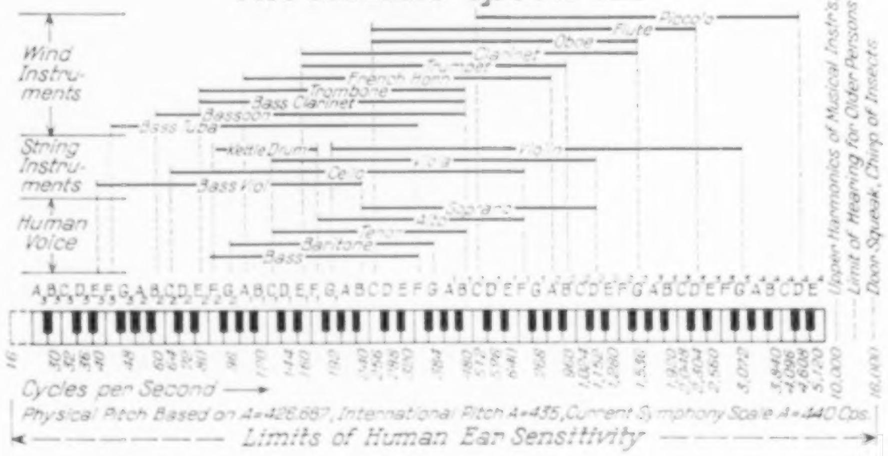
The Radio Spectrum



The Ether Spectrum

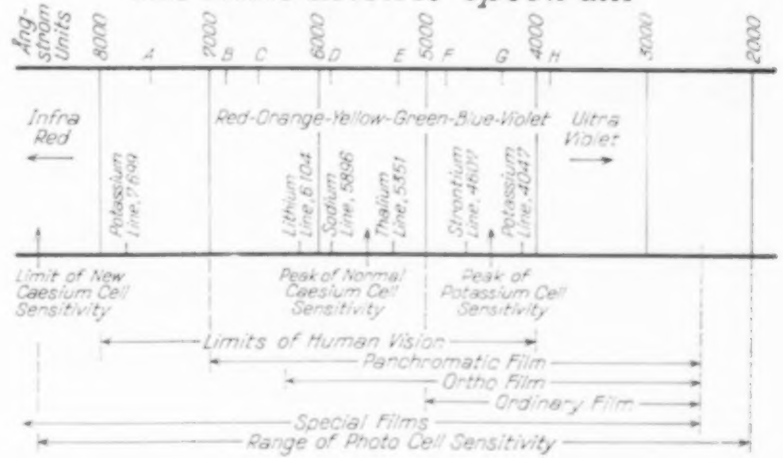


The Audible Spectrum



Reproduced by Courtesy of "Electronics"

The Photo-Electric Spectrum



By W. A. James
Chief Engineer, Lackawanna Plant
Bethlehem Steel Company

Modern pickling units in new Bethlehem sheet mill

PICKLING, as a process of removing the scale from metal by submerging it in a dilute acid solution, dates back to the middle ages. In the 17th century Bohemian tinsmiths employed this method to remove oxide from hand-wrought iron sheet, preparatory to tinning it, and this is basically the same method by which strip-sheet is pickled prior to cold rolling into automobile sheets and other flat sheet-strip products in the two 500-ft. pickling lines in Bethlehem's new strip-sheet mill at Lackawanna, N. Y. However, in size and capacity these highly mechanized units differ as profoundly from the primitive equipment employed in Bohemia as the Queen Mary differs from a birch bark canoe!

In these two modern units a long ribbon of steel, as it comes from the hot mill division, moves at the correct pace through four 60-ft. acid tanks and two 25-ft. wash tanks; then to an oiling machine and recoiler, whereupon the hot-rolled strip-sheet is completely pickled. In this condition it is ready for further processing; this usually includes reduction in gage and physical refinement by cold rolling, box annealing and a "skin pass" (such a program being varied according to the purposes for which the steel is to be used). The two pickling lines each have a rated capacity of 13,000 tons per month, and are designed to handle strip in any width up to 72 in.

In greater detail, the arrangement of equipment in each unit, referred to as a "pickling line," consists of a coil up-ender, an uncoiler or feed reel, a scale breaker or processing machine, a shear, a stitching machine, pinch rolls to feed a looping pit, pinch rolls to maintain tension on the strip ahead, four acid tanks, two water wash tanks, a pair of pinch rolls for pulling the strip through these tanks, a shear to separate the rolls at their stitched ends, an oiling machine and a recoiler, all of which are arranged in tandem formation for the passage of an endless ribbon of metal.

Since they weigh up to 12,000 lb., each coil of strip-sheet necessarily is handled mechanically as it is taken from storage and entered into the pickling line. Coils are lifted by magnet to the coil up-ender, a cradle mounted in a circular cradle (shown in the left background in the first view on page 65) and this device then places the coil on its side for rolling to the uncoiler or feed reel. From the feed reel the strip passes to a processing machine where the deposit of scale or oxide on its surface is loosened by passing through a series of rollers causing several sharp reverse curvatures across the width. Then it advances to shear and stitching machine where the uneven end is cut square and successively each coil is fastened to the end of the preceding coil. The stitching machine cuts out or punches a row of tabs in the overlapping coil ends, bending them back and then flattening them down, just as sheets of paper are frequently fastened together in business offices. Thus the tail end of each coil of strip as it passes through the pickling line is joined to the front end of the coil that follows.

The pickling line from up-enders to recoilers measures 500 ft. While the strip-sheet is passing through the acid tanks it is imperative that its speed be accurately controlled, for variations in its passage through the acid would cause corresponding variations in surface development. Too slow might result in an open surface; too rapid would not remove all the scale. This control is effected by an intricate electrical system, so arranged that the entire pickling line is operated from only two desks, one located at either end.

It is at the point that the strip-sheet enters the acid that its speed of travel must be fairly constant. Since the stitching and shearing operations are of an intermittent nature, a looping pit is provided between the stitching machine and the hold-back pinch roll at the entrance of the first acid tank. Here sufficient slack is provided so that processing speeds can be maintained while the strip is stitched.

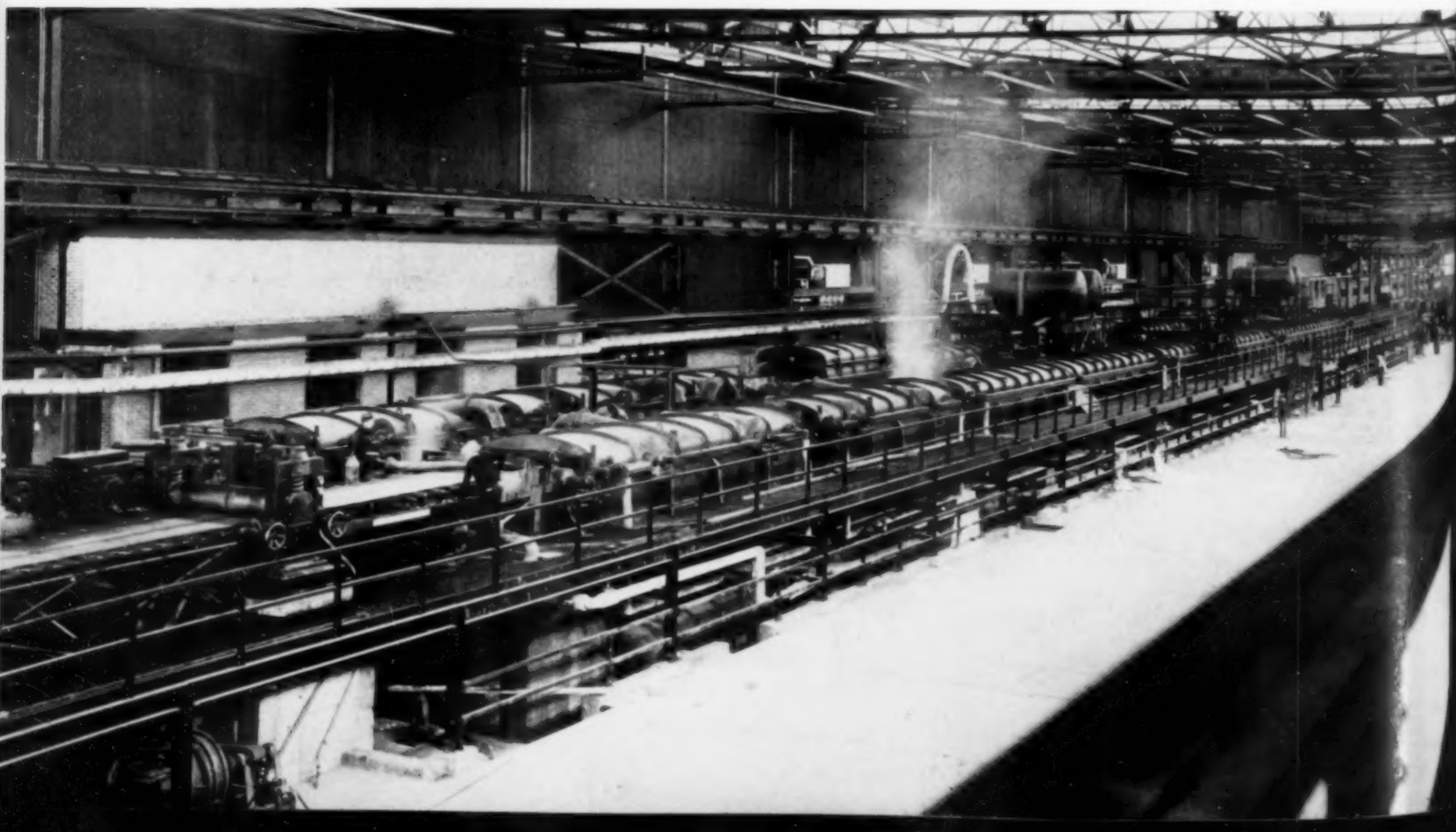
Tops of the acid pits are elevated about 10 ft. above the floor of the building. Entering the acid tanks, each of which are 60 ft. long by 84 in. wide, the strip moves forward at a speed of 52 to 156 ft. per min., depending upon the width of strip and amount of scale to be removed. An 8 to 12% sulphuric acid solution is usually employed, although the pickling agent can be hydrochloric, or nitric, or these three acids in combination.

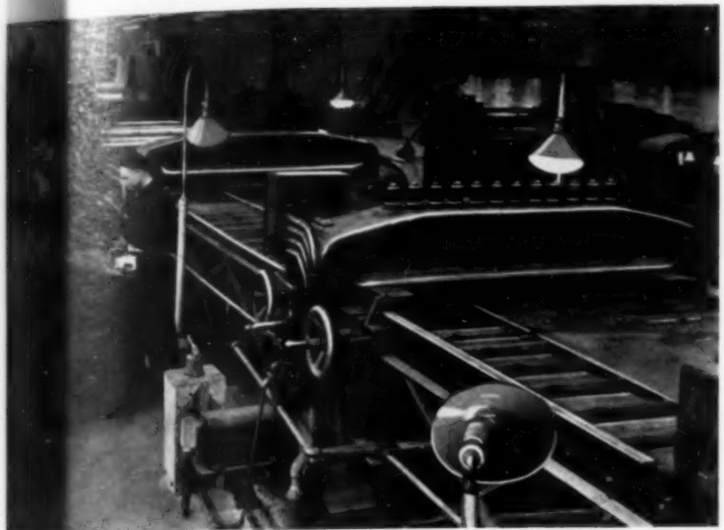
The temperature of the acid bath is usually maintained at about 180° F. Steam admitted to the bath through monel metal jets is used for heat. Since accurate control of its temperature is of utmost importance to assure uniform pickling, or to prevent excessive loss of acid from too high temperature, thermocouples protected from the acid by monel metal tubes are submerged in the bath and automatically actuate motor-operated valves in the steam lines, admitting steam as required to keep the bath at the desired temperature. Indicating thermometers showing the temperature of the baths in each tank are also located within view of the operators.

As the strip passes through each of the four acid tanks the acid solution attacks the scale (and, in part, the metal under the scale) forming iron sulphate and hydrogen. The latter aids in loosening flakes of oxide, which in part is dissolved and in part drops off. After each submerging in the successive tanks, the strip loses more and more of the surface impurities, until upon emerging from the last tank, it is clean except for such acid solution as adheres. It then enters the two water tanks which serve to remove the remaining traces of acid. The first of these contains cold water, continuously replaced to avoid contamination with acid. Then it is submerged in a hot water bath, the principal purpose of which is to heat the strip so it will dry quickly. Leaving the last water tank, drying is hastened to prevent rusting by blowing warm air on the surface.

The strip now continues through another set of pinch rollers which has been pulling the strip through the six tanks, and moves forward

Pickling Building at New Lackawanna Sheet-Strip Mill Is 925 Ft. Long and 105 Ft. Wide, Contains Two Parallel Units and Can Clean Nearly 1000 Tons of Metal a Day





1 *Control Desk at Leading End of Line Which Begins With Coil Up-Ender at Extreme Left, Roller Leveller for Scale Breaking, Shear for Squaring Ends and Stitching Machine in Foreground. Sheet-strip then passes to an ample looping pit*

2 *Acid Tank With One Section of Arched Cover Removed to Show Interior Construction. Steel container has three layers of rubber vulcanized on and a two-course brick lining. Numerous expansion joints are provided in rubber and brick*

to a shear, which cuts out the stitches, during which time the strip is stationary.

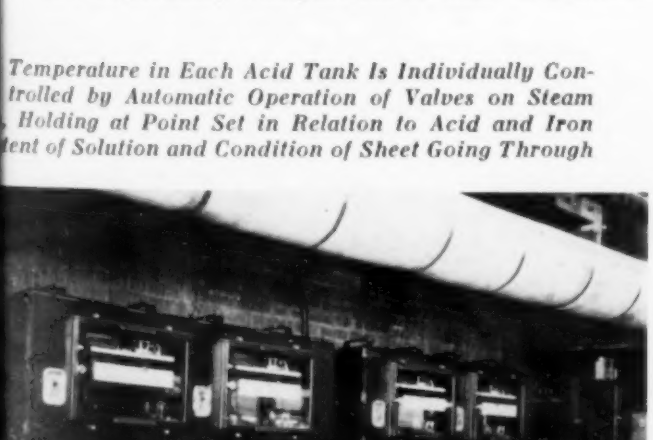
The strip then enters an oiling machine, spreading oil over the surface top and bottom, and on to a machine where the strip is rewound into coil form again, after which it is weighed and delivered to the cold mill in a clean condition for cold rolling.

The chemical reaction which occurs in the pickling process becomes somewhat difficult to control, and since the action of the acid solutions is destructive by nature, naturally the tanks containing the bath are easily a target for attack. For years, the rapid deterioration of pickling plant equipment has presented a serious problem to engineers and operators; much effort has been expended to determine materials capable of withstanding the destructive elements, and provide equipment with a life expectancy comparable to that of machinery used in allied operations, and at the same time provide an atmosphere for workmen that would be free from obnoxious fumes.

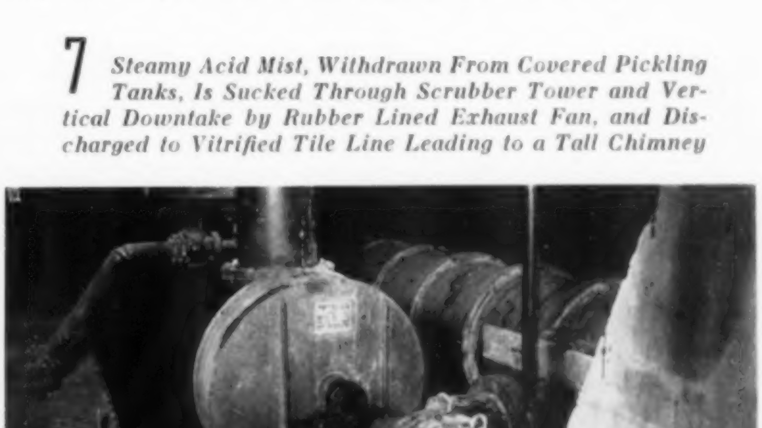
Careful consideration was given to these problems in the construction of the pickling department at the new Bethlehem mill, with a resulting ideal set of conditions.

Each tank containing the heated acid bath is made in the form of a steel, box-like shell, 61 ft. 5 in. long by 8 ft. 6 in. wide and 4 ft. 8 in. deep. The steel is protected by a lining of rubber vulcanized over its interior surface. It was necessary to build the rubber lining on the tank in layers; first a layer of soft rubber was vulcanized directly against the steel to provide a satisfactory bond between the steel and rubber; on this followed a layer of hard rubber which is practically impervious to the acid solution; finally a third layer of soft rubber was applied to provide a bond between the hard

Temperature in Each Acid Tank Is Individually Controlled by Automatic Operation of Valves on Steam , Holding at Point Set in Relation to Acid and Iron Content of Solution and Condition of Sheet Going Through



7 *Steamy Acid Mist, Withdrawn From Covered Pickling Tanks, Is Sucked Through Scrubber Tower and Vertical Downtake by Rubber Lined Exhaust Fan, and Discharged to Vitrified Tile Line Leading to a Tall Chimney*

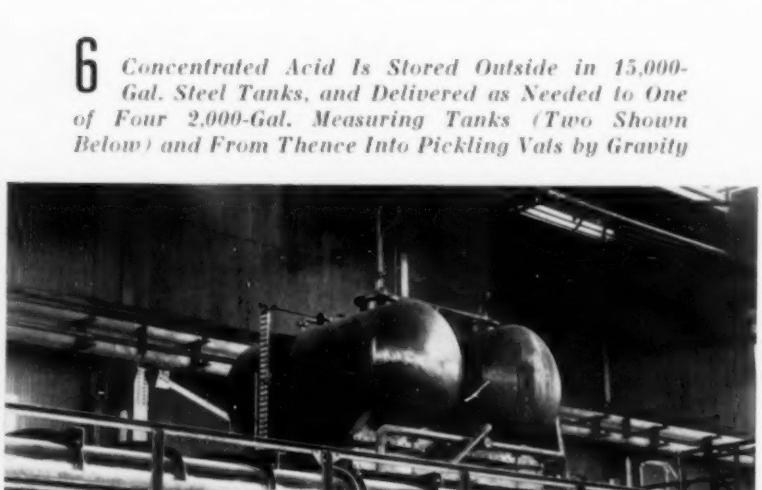


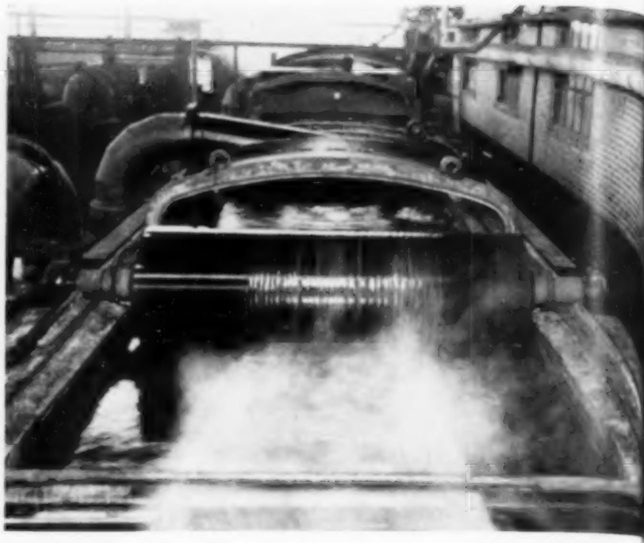
3 *Rubber-Covered Rolls Are Installed Near Ends of Tanks to Hold Down the Taut Strip Below Surface of Liquid; Others Are Placed Between Adjacent Tanks. All tanks, even wash tanks, are tightly covered and connected to exhaust system*

rubber and the protective brick sheathing. The layers of rubber were built up in about 3-ft. sections across the tank, with joints to provide for the proper expansion when the lining was heated. The thickness of the three layers of rubber totaled ¼ in. To protect the rubber from abrasion and to act as a heat insulator, a brick lining 8 in. thick was built on the interior of the tank of hard burned brick impervious to acid. The brick are laid up in two courses, cemented with an acid resisting cement having a sulphur base; expansion joints are provided in the walls, to allow for growth in the lining when subjected to the high temperatures. (These details are shown in the second photograph at left, above.) The tank bottom slopes so that it can be completely emptied.

The construction of all tanks, including the water wash tanks, is identical. As already noted they are placed in tandem and spaced 3 ft. 4 in.

6 *Concentrated Acid Is Stored Outside in 15,000-Gal. Steel Tanks, and Delivered as Needed to One of Four 2,000-Gal. Measuring Tanks (Two Shown Below) and From Thence Into Pickling Vats by Gravity*



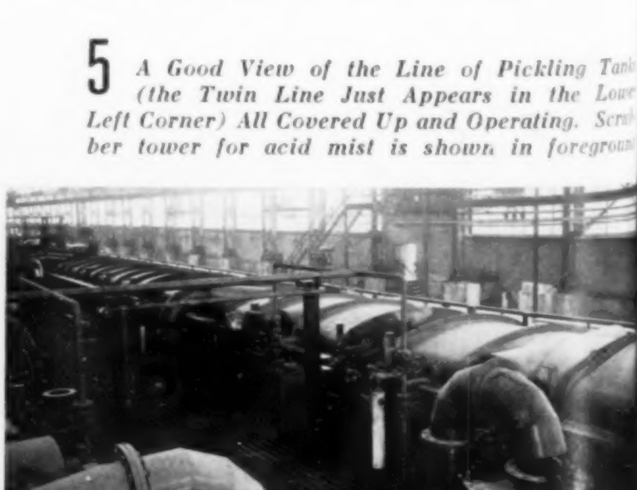


4 *Strip Leaving Last Wash Tank (Hot Water Blasted With Hot Air and Enters Group of chines Shown on Next Page. Pictures 5 to 8 be show various auxiliaries on the main pickling*

apart; in this space is located a carrier roll, covered with rubber, over which the strip rides in its passage from one tank to the other. A steel drip pan, lined with rubber, is provided under each carrier roll to catch any acid that may drip from the strip, and is drained to the sewer through a rubber hose.

Tanks are emptied by combination syphons and overflows constructed of lead. A syphon is preferable to a bottom outlet in a tank, since it diminishes the possibility of losing acid through a leaky stopper; likewise the outlet does not become clogged by the copperas crystals or sludge formed in the process. The syphons discharge through lead pipes into a semicircular steel launder, rubber lined, that runs the entire length of the pickling line, and after leaving the building discharge into an 18-in. chemical stoneware pipe, and are drained into a large pit, brick lined, for disposal. The

5 *A Good View of the Line of Pickling Tan (the Twin Line Just Appears in the Low Left Corner) All Covered Up and Operating. Scru ber tower for acid mist is shown in foregrou*



rubber lined sewer is provided with all-rubber expansion joints at 100-ft. intervals to permit expansion and contraction of the metal shell.

Tank tops are 10 ft. above the main floor level, and working platforms of subway grating are built at about the level of their bottom. The bottoms of the tanks clear the floor about 5 ft. and the sewers, pipe lines, pumps and other machinery serving the tanks, are all carried underneath in an open cellar, so that all important parts of the units are open and easily accessible to facilitate inspection and repair.

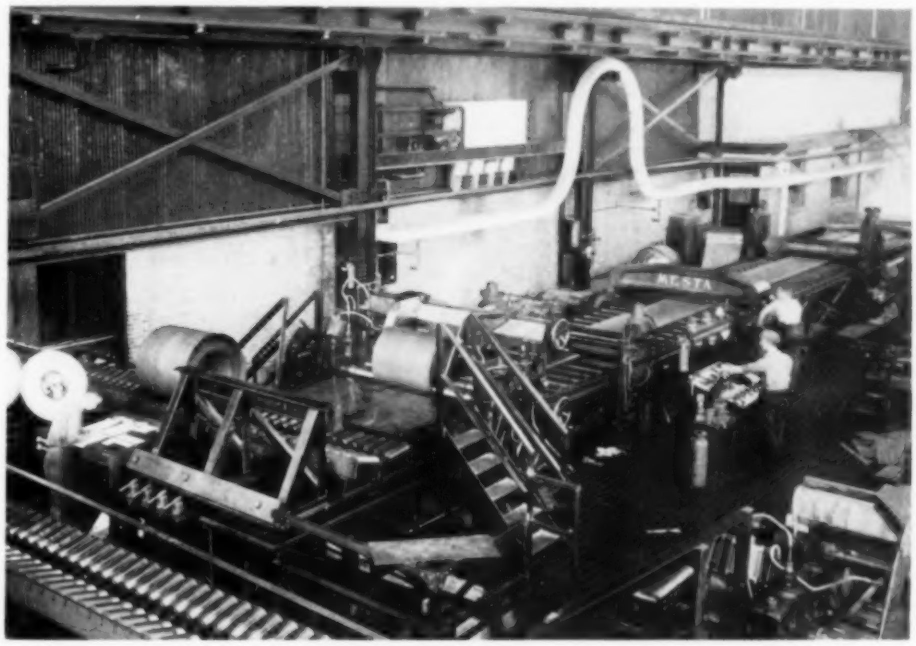
Having provided a satisfactory system for handling and disposing of the pickling solution, attention was given to removing the obnoxious fumes and acid mist.

This was accomplished by covering the tanks with arched steel covers, rubber lined, made up in relatively short sections so as to be easily movable. An exhaust system for removing the fumes was applied to each tank; it consists of a fan of 4500 cu. ft. per min. capacity which draws the fumes from the tank through rubber lined ducts 16 in. diameter. Fumes from the tank pass through a scrubber which is a steel, rubber lined tank 3 ft. in diameter and 7 ft. high, at the top of which is located a series of water atomizers, serving to spray the gases and remove, to a minimum, any acid contained. Leaving the scrubber, the exhaust enters a rubber lined exhaust fan, and discharges into a single line of large vitrified tile sewer pipe, serving all six tanks, which in turn vents the gases, now practically acid free, to the atmosphere through a high stack constructed of asbestos protected metal.

So effective and complete is this system that in travelling through the building there is no evidence of a pickling operation, insofar as obnoxious gases or vapors are concerned.

Each of the acid tanks is emptied at fairly regular intervals, usually about a week apart; the exact time is determined by the tonnage of steel that has been pickled and the iron content of the solution. At the proper time the solution is entirely removed and replaced with a fresh charge of acid and water. On account of the large volume of liquid in each tank, about 11,000 gal., a hot water reservoir provides a supply of preheated water; this avoids the usual delay required to bring this quantity of water up to pickling temperature. In this manner the effective capacity of the pickling line is kept to a maximum.

For the solution, concentrated sulphuric acid is blown through an acid egg from a 15,000-gal. storage tank located outside the building, into one of four measuring tanks each having a capacity of 2,000 gal. These tanks are adjacent to and above the pickling tanks and the acid is transferred from them by gravity.



Discharge End of One of the Pickling Lines, Showing (Right to Left) Tension Rolls, Shear for Cutting Out Stitches, Oiling Machine, Recoiler and Scales Under Conveyor Leading to Cold Mills

All the machinery used in this department is of the most modern design. Its arrangement has been designed to facilitate handling of the product in the most efficient manner. The building is 925 ft. long by 105 ft. wide, of standard steel frame construction with walls of brick and glass; particular attention has been given to light and ventilation. For the cold winter months, unit heaters, steam operated, will provide a uniform temperature. Three 15-ton overhead travelling cranes handle the coils from storage and to the pickling line.

Correspondence and foreign letters

A New Effort to Determine Non-Metallic Inclusions

SHEFFIELD, *England* — It would seem to be clear beyond any doubt that the properties of steel produced in any steel making furnace — and whether in the cast condition or after working — are affected to a considerable extent by actual conditions in the steel making furnace, and particularly by the degree to which the steel was oxidized during the removal of impurities, the efficiency of the subsequent deoxidation and the character of the deoxidizers used. However carefully these operations are carried out, the finished steel always contains a small but variable amount of oxygen, the bulk of which exists as oxides mechanically mixed with the steel, though probably a very small amount is in solution in iron.

The amount of dissolved oxygen is largely a function of the degree of deoxidation, but the quantity, character and physical condition of the non-metallic inclusions in the solid steel are affected, in all probability, not only by the final deoxidation period but also, in greater or less degree, by the earlier conditions in the steel making furnace.

It seems very probable that if one could determine accurately the amount and character of the non-metallic inclusions present in a number of steels of similar analysis, as ordinarily reported, but which had been made under different but carefully observed and controlled steel making conditions, and could correlate this information with various physical properties of the several steels — for instance, their notch toughness, their grain size and rate of grain growth at different temperatures, and their hardening characteristics — one would have a key to many of the differences observed between steels of apparently the same composition.

Such an idea is not new, of course; it has been the driving force behind many of the most recent investigations both on steel making conditions and on the estimation of non-metallic inclusions in steels. With regard to the latter problem, a number of methods have been proposed but it is notorious that they have given widely differing results even in the hands of careful experimenters, and hence there are doubts as to which, if any, of these methods of estimating inclusions are likely to be correct.

It is interesting, therefore, to study the paper on "The Determination of Non-Metallic Inclusions in Steel and Iron," recently presented by Colbeck, Craven and Murray to the British Iron and Steel Institute. These investigators confined their attention to methods involving chemical attack on the steel, which allowed them to separate, collect and analyze the non-metallic residues. For this purpose they used iodine in alcoholic solution (the method described in 1935 before the Institute by Rooney and Stapleton), chlorine at 500 to 1000° F., dilute acids, and an acid solution of copper ammonium chloride. Dilute nitric acid was discarded as impracticable owing to its very slow rate of attack; dilute sulphuric and hydrochloric acids and also the copper ammonium chloride solution were shown to attack certain inclusions and hence to lead to low results.

(Continued on page 88)

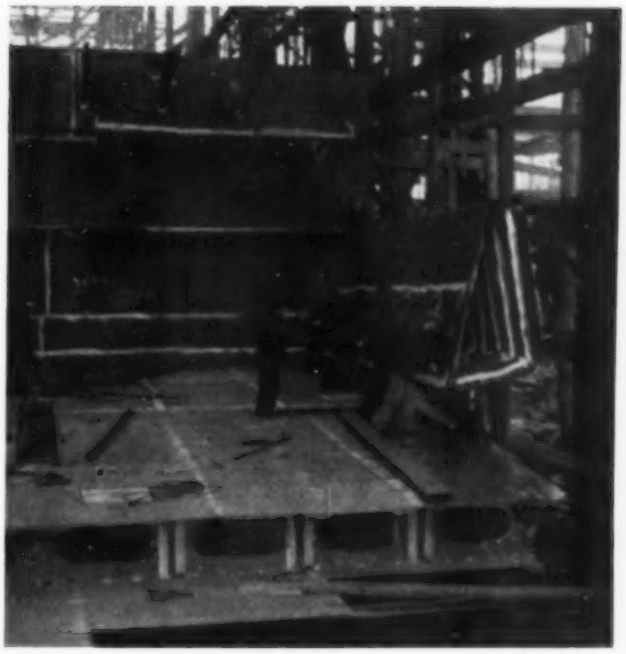
An All-Welded Ship

Posthumous Contribution from F. G. Martin

LIVERPOOL, *England* — I contributed an article on all-welded ships to the issue of Metal Progress for September 1935. There followed two months later a letter from Walter E. Quine, naval architect to the Quasi-Arc Co. Ltd., pointing out that I had perhaps not done justice to the question of the size of the vessels which could be so constructed. Following Mr. Quine's letter is a note by the Editor that the Joseph Medill, then the biggest all-welded ship, was a month overdue and was believed to have foundered.

An inquiry into the loss of this ship was eventually held at Newcastle-on-Tyne, England, and the case was as fully investigated as was possible in the absence of survivors or material evidence. While the court found that the real cause of the disaster remained an unsolved mystery it was decided, after full consideration of the circumstances, that the most probable cause of the loss was that the vessel had struck an iceberg and then sank very rapidly.

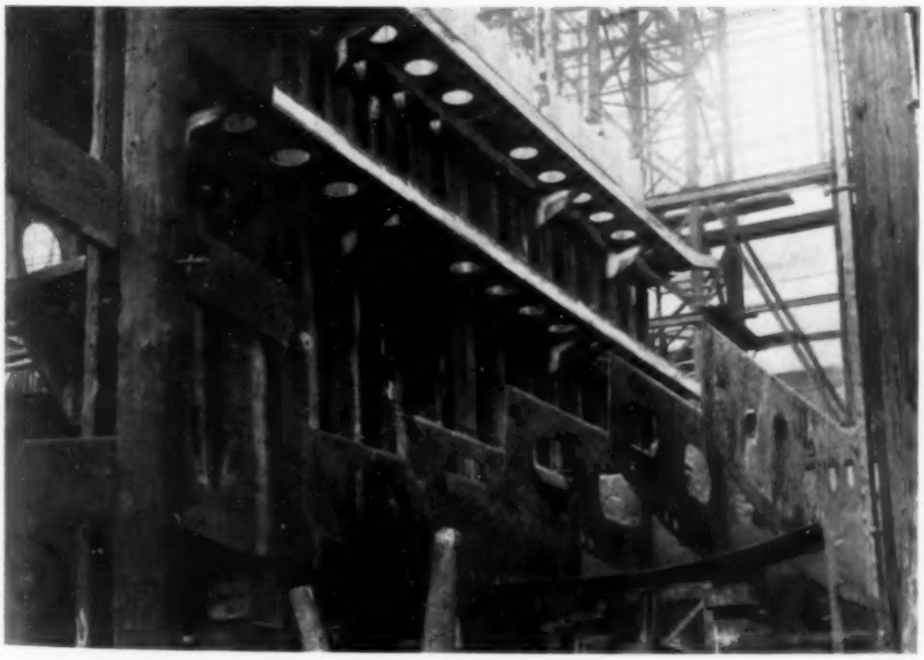
There will, of course, be a section of the shipping public opposed to electric welding who will see in this disaster an argument against welded ships. The argument, of course, may equally well be turned aside and the loss ascribed to the fact that the ship was fitted with Diesel engines! The fact still remains that her owners are unshaken in their faith in the welded ship, so that an equivalent vessel was immediately ordered for the same service. One must also bear in mind that there are now very many other welded ships and barges, all giving adequate service and there is no reason whatever to suspect that the catastrophe was due to the fact that the ship was all-welded.



Section of Double Bottom Erected, and Men Swinging Pre-Fabricated Portion of Bilge Tanks Into Place

It is a matter of regret that the vessel was not fitted with wireless. Wireless was not compulsory because she was for service on the Great Lakes. Again, the utter disappearance of all material evidence is strong proof of the suddenness of her loss, and rather suggests that even if she had had wireless, help could not have arrived in time.

The ship to replace this was launched early in April from the yard of Messrs. Swan, Hunter & Wigham, Richardson. She was christened Franquelin; her dimensions are length 259 ft.,



Motor Vessel Franquelin, All-Welded. Bulkhead, showing stiffeners and fore-end framing. All photos courtesy Quasi-Arc Co., Ltd.

breadth 43 ft. 6 in., with a moulded depth of 22 ft. She is classed A.1 at Lloyds for service in the Great Lakes and the Gulf of St. Lawrence. The method of construction was very largely similar to that used for the Joseph Medill and detailed in my previous article.

Her design incorporates the patent "conduit bilge" system which has been introduced with great success in several ships recently built for service on the Great Lakes. The advantages claimed are many, among which may be mentioned extra protection to the region of the bilges, the accessibility through the entire length of the ship for cleaning and painting and the provision of a convenient passage for leading suction pipes to tanks and hold. The inner diagonal boundary of the tanks provides self-trimming facilities for the bulk cargo, and also forms a strong longitudinal girder in the most useful position.

The ship has a cruiser stern, twin rudders of balanced streamline spade type and twin screws driven by two Diesel motors. The cargo space is divided into four holds by watertight bulkheads and has four large hatches. The double bottom is divided into two tanks and the conduit bilge into two separate tanks each side. Framing is arranged transversely except for the fore end where a system of cant frames is substituted. No stem bar is fitted but in its place a heavy shaped plate is introduced to which the shell plating is attached.

In this, as well as the steamship Moira, the largest all welded oil tanker, the greatest advance in design is the butt welding of shell plating, including longitudinal joints (ordinarily riveted laps even in vessels otherwise welded). The base of the conduit bilge is in the same plane as the bottom plating; its hypotenuse forms the hopper corner of the hold, and the outer vertical is welded to the side shell panels; the stiffeners of the latter rest on the narrow ledge at top of this triangular member.

All deck machinery is electrically driven.

Franquelin, Under Construction. The largest lake cargo ship, all-welded, Diesel driven. Four holds, with very large hatches, are designed for carrying wood pulp and newsprint

Windlass, winches, steering gear, refrigerating machinery, galley range, all cabin heating and hot water heater are powered by electricity.

The propelling machinery consists of two sets of single acting, two cycle, mechanical injection Diesel engines of Sulzer make, having a combined minimum brake horsepower of 1000 at about 350 r.p.m.

F. GRIMSHAW MARTIN

25th Anniversary of Dr. Honda's Professorship

SENDAI, *Japan* — Prof. Kôtarô Honda, President of the Tôhoku Imperial University, has been on the faculty of this university for 25 years, and in order to celebrate that anniversary of this great scientist, his friends and pupils organized the Honda Anniversary Committee. The celebration was attended by Professor and Mrs. Honda and their family, prominent scientists in the country, high state officials, and other guests to the number of nearly 600; it was held on May 31 in an auditorium of the university, and it certainly was a gala event in the history of the university. The forenoon of the day was devoted to the anniversary ceremony. The main program consisted of an opening speech, a report on the progress of the university work, the unveiling of a statue of the guest of honor, the presentation of remembrances, commemoration addresses, the announcement of congratulatory telegrams, and a response by Professor Honda. After the ceremony, brief commemoration lectures were given by three prominent scientists, and then a luncheon was held. In the afternoon, all the guests visited the Research Institute for Iron, Steel and Other Metals, the home of Professor Honda's research laboratory, where they were impressed anew with the greatness of the man and of the work that he has done.

On the next day, the members of the Physics Department and of the Research Institute invited Professor and Mrs. Honda and their family for an informal picnic to Matsushima, which is not far from here and which is one of the most famous places in Japan for its natural beauty. On the following day, papers on important researches by his former pupils were read at the main lecture hall of the Research Institute.

Thus for three days we held a whole hearted celebration of this happy event and prayed to God that Dr. Honda may be endowed with continued excellent health and that he may render even greater service to the science of the world.

The Honda Anniversary Committee, the funds of which amounting to over 300,000 yen were contributed by his friends and pupils, is carrying out the following plans: To endow the Honda Memorial Laboratory; to erect Professor Honda's statue, unveiled at the ceremony; to endow the Japanese Institute of Metals; to establish the Honda Medal to be awarded annually from the Institute to some one, irrespective of nationality, who has rendered distinguished service to the science of metals; and finally to publish the Honda Anniversary Volume, the manuscripts for which were kindly contributed by leading scientists in Europe and in America as well as by those at home.

KEIZO IWASE

Adherence of Antifriction Alloys in Bushings

PARIS, *France* — Adhesion of a metallic coating upon another metal may be the result either *(a)* of simple molecular attraction, *(b)* of mechanical attachment or interpenetration of the surfaces in contact, or *(c)* of an alloying action — that is to say, interpenetration by diffusion of atoms of the metals themselves.

Adhesion solely by molecular attraction is rare between solid metals, although it is common between a solid metal and a liquid metal which "wets" it. A perfect contact must be obtained between solid metals without the slightest interposition of gaseous or liquid films and without altering the surface; this type of adhesion is approached when gage blocks are wrung together, but it is very difficult to obtain even in electroplates. Mechanical attachment of the electrolytic deposit to the underlying metallic surface is therefore often sought, the surface being first roughened, either mechanically by sanding, for instance, or chemically by pickling the surface.

In sticking objects together with glue, there is both a molecular attraction and a mechanical adhesion by the penetration of glue into the irregularities, pores and rough spots of the abutting solid surfaces.

In the case of metals, however, the most practical method is to obtain metallic interpenetration by alloying. That is what takes place when coatings are obtained by dipping an object into a molten metal such as in tin-

plating or galvanizing. An even better example is autogenous welding, where there is simultaneous fusion of the two metals being joined. This alloying action can even be obtained in the solid state by mutual diffusion, accelerated by heating or by pressure.

To form an intermediate layer and assuring a continuous connection between two metals, *A* and *B*, the alloy could be either a solid solution or an intermediate phase of the alloy system *A-B*, depending upon the nature of the metals *A* and *B* and the conditions under which the intermediate layer was obtained. If a solid solution is formed, the coating is malleable to the same degree as the constituent metals *A* and *B* are malleable, and adhesion is maintained in spite of the inevitable deformations and vibrations encountered in service. On the other hand, intermediate phases are of a more or less metallic nature, and are often brittle. In the latter case the junction may be broken in service by rupture of the intermediate layer, or even by solidification shrinkage after the operation is completed.

This is what happens to antifriction alloys, applied by the well-known operation of babbitting, in very thin layers (often only a few tenths of a millimeter), inside sleeves of steel or bronze to form bearings for modern motors with very minute clearance between the shaft and the rubbing surfaces. Adhesion of the antifriction alloy lining to its backing may be prevented by oxidation or dirtiness of the surface of the latter, or by the formation of a brittle compound resulting from the combination of the tin or other metals of the antifriction alloy with the iron of the steel backing or sleeve, or with the copper of the bronze backing.

As a consequence the antifriction alloy or babbitt does not retain a close grip on the base metal; it laminates or flakes off when loaded.

To avoid such serious difficulties, attempts have been made to interpose between the two metals *A* and *B* (in the present example the antifriction alloy and the backing) a third metal or alloy *C* capable of forming intermediate solid solutions with both *A* and *B*, thus serving as a bond between them. *(Continued on page 82)*

Do you recognize this metal working plant?

We are again offering an enlarged airview of the above plant to the first six who send in correct identifications. The one published last month has been spotted by a considerable number of readers as the McCormick Works of International Harvester Co., Chicago, Ill. The first six to reach the Editor were from Norman H. Davies, Chicago; Frank Monaco, Lorain, Ohio; Albert P. Meissler, Chicago; Edward P. Geary, Pittsburgh; Roger Dexter, Chicago; and K. H. Hobbie, Chicago, and through the courtesy of Harry H. Harris — business man, flyer, photographer — photographs have been sent to them.

Liquid Brazing

By J. M. G. Turnbull

C. A. Parsons & Co., Ltd.

Condensed from The Engineer, Dec. 11 and 18, 1936

A STUDY of this old process for fixing blades to steam turbine rotors was necessary when stainless iron (13.5% chromium, 0.12% carbon max.) was substituted for mild steel blades. Blades made of the new material are more difficult to braze to the mild steel packing sections at their roots. The operation consists of wiring together 10 to 12 blades with the required spacers and shrouding at ends and then immersing this composite segment through a molten layer of borax flux into a pool of 70:30 brass.

Good brazing can be obtained only on scrupulously clean metallic surfaces. Degreasing the blades is all that is necessary, but the mild steel spacers must be free of rust. A complicated set of seven operations was used to attain the latter object; it also involved the use of a poisonous cyanide solution. Laboratory studies indicated that a variety of pickling solutions would give a much simpler program, but in the plant atmosphere the rate at which the clean surface rusted was much faster. Eventually the following treatment was installed with good results: Immerse 10 min. in 10 to 15% nitric acid solution, then dip in concentrated nitric acid, wash and dry. The concentrated acid not only removed the carbon deposit left behind by corrosion in the dilute pickle, but also passivated the surface against rust.

In the old practice the segments were suspended on a hook attached to a long arm. The position of the arm is regulated by a motor-driven cam, so that the roots of the segment dip successively into the borax and brass, up and down during definite intervals of time. The melt is contained in a crucible made of graphite and fireclay, and heated either in a coke fire, a gas flame or by induced electricity.

Borax corrodes the container badly, and this is provided for by special crucibles with double thickness of walls at top, or by using a stainless steel liner extending below the borax bath. The use of liners is not without disadvantages, however, for the borax attacks the steel, increasing the iron content of the flux considerably. This decreases its fluidity, and also its cleansing powers, hence necessitating its being renewed more frequently. Perhaps a more serious disadvantage is its effect on the brass. This also absorbs iron, being in contact with the borax, rich in iron. The iron content of the brass is not allowed to exceed 1.5%, and when this figure is reached, half of the metal is replaced by new. Incidentally, this equilibrium can be utilized in the opposite direction by changing the borax daily. Hence, it can be seen that the real economy of liners is based on two opposing factors:

1. Without liners, the pots have to be replaced more often, while the brass has to be changed less often.
2. With liners, the pots last longer, but the brass has to be changed more often.

The balance is in favor of liners with standard crucibles, this representing a saving of about 65% of the old cost of containers, brass and borax.

Serious efforts have been made to improve upon borax as a flux. Its corrosive effect has been mentioned above. Reports from the blade shop have stated that in order to attain the fluidity required for successful brazing the borax has to be maintained at high temperatures (of the order of 1950 to 2000° F.) because the viscosity increases rapidly with decrease in temperature. The validity of this statement will be discussed later.

An attempt to supersede borax with a patent flux led to interesting, although very disappointing results. This flux had been used for some time for hand brazing work; it consisted of 60% boric acid and 40% ordinary borax, with the addition of a little red organic dye. It appeared to possess several promising features, particularly in prolonging the life of the crucibles. It was found, however, that the brass cast after being under this flux for a week was quite porous, having a breaking strength as low as 8000 psi. and 1.0% elongation, whereas brass having been under borax for a week would break at 35,000 psi. or higher with 20% or greater elongation. Strength of the bond in brazed joints showed similar relations. It was suspected that this might be due to evolution of water vapor from the boric acid, or the absorption of gas from the heating chamber through the crucible walls, but it appears more likely that the boric acid (or boron trioxide, its decomposition product) reacts in some manner with the brass.

After the failure of this flux, experiments were carried out to find another to supersede borax. In addition to having cleansing properties equal to borax, such a flux was required to give a thinner melt, thus enabling lower temperatures to be used, and also to prevent the slight attack on the stainless iron blades which took place at the air surface of the borax. As this latter defect with borax was in all probability merely due to oxidation, a flux allowing of lower working temperatures would lessen such attack. It was attempted to create a reducing atmosphere at the surface of the borax by a layer of charcoal, which resulted in a slight improvement.

In attempting to find a thinner flux, the viscosity had to be measured, and this was done as

follows: The molten flux was held in a suitable container in an electrically heated pot furnace. Into it was suspended a crossed vane of platinum sheet by a 35-gage iron wire, 32.5 in. long. Five complete twists were given this wire, thus establishing a standard torque, whereupon the vane was released and the time to make one turn (as indicated by a pointer above the furnace) was measured by a stop watch. This time is related to "Redwood viscosity", as shown by a preliminary calibration with oil of known viscosity.

Experiments at various temperatures were made on several proposed substances and mixtures, both chemically pure and after several hours' use in brazing operations. Curves are presented in the original article showing the temperature-viscosity relationships, from which the following are taken: Temperature to give viscosity of 8.0 units (arbitrary scale): 1525° F. for 80% borax plus 20% fluorspar; 1550° F. for borax; 1590° F. for borax plus 10% fluorspar; 1700° F. for 90% borax with 10% sodium silicate; and 1800° F. for 40% borax with 60% boric acid. It is thus seen that shop reports about the fluidity of the patented mixture were incorrect. With a slightly different setup another series of curves was derived, and from these the following data are scaled: Viscosity at 1450° F.: 2.5 for a mixture of 40% borax, 30% sodium carbonate and 30% potassium carbonate; 6.7 for 90% borax with 10% sodium sulphate; 20.0 for fresh borax; 22.0 for 80% borax with 20% fluorspar; 27.5 for borax after 12 hr. brazing; 33.0 for borax after 24 hr. use in the brazing operation.

Lower Temperatures Possible

The results of these experiments show that as far as viscosity is concerned, borax should be quite suitable for brazing at as low a temperature as 1750° F., even when it is contaminated to such an extent that it is considered unfit for brazing (that is, after 24 hr. use). It then has a viscosity of less than 4.0 on the arbitrary scale. Thus, it would seem quite possible to braze at much lower temperatures than at present, for borax at 1750° F. corresponds to a brass temperature below, of about 1900° F. This lower operating temperature would minimize the evolution of zinc and the attack on the crucibles and blades, and in addition would save fuel. This temperature, which is 150° F. above the freezing point of the brass, should be high enough to prevent any setting of the brass on immersion of the segments, as the temperature of these has been raised to the borax temperature before entering the metal. It may, however, necessitate a slightly longer time of dipping.

As is well known, the brass used for brazing is quite pure at the start, analyzing about 70% copper and 30% zinc. Microstructurally it is a solid solution. It rapidly picks up iron, which increases the strength but also embrittles the alloy when solid; hence a sample of the metal is taken daily, on which the iron content is estimated, and as soon as this reaches 1.5%, 50% of the metal is changed for new. At the temperatures used in brazing, the partial pressure of zinc in brass is high. Hence much is lost by volatilization, and the copper content rises. This is kept as near 70% as is possible by daily analysis and the subsequent addition of zinc.

In an attempt to reduce the volatilization of the zinc, the experiment was tried of adding 1% aluminum to the melt. It was known that such an addition in casting processes results in a thin, but very tenacious surface film of alumina, which prevents loss of zinc. However, a thick crust formed on the metal, under the borax, which proved to be aluminum oxide mixed with borax and brass. Hence it is not feasible to add aluminum to an alloy melted under borax.

Mention has already been made of the mechanism used for performing the brazing operations. It seemed to be unnecessarily complicated. It was considered that only two operations were needed:

1. The segments to be immersed in the flux for a sufficiently long period as would enable them to attain the borax temperature.

2. To be then lowered into the brass, and held there until all the borax had been replaced by the molten brass.

This latter time was considered to be comparatively short, say 30 sec. When the time necessary to preheat (time for immersion in the borax) was determined for assemblies of various dimensions, it was found that new cams giving a single dip would be satisfactory, and the time of the operation was decreased about one-quarter.

After brazing, the segments are covered with a coating of borax glass. To remove this, the segments used to be boiled in a caustic soda solution. This solution was obviously useless for the purpose, borax itself being alkaline in nature, and the segments were 24 to 48 hr. in the bath before the borax was dissolved. Treatment with an acid bath would appear to be the most suitable procedure. Trials with various acid combinations indicated that borax could be removed without any attack on the metal in 7 min. in a boiling solution of 3% nitric acid plus an organic inhibitor.

Lastly, the very important relationship between quality of joint and thickness of brass layer was studied. It was found that the bond was poor and strength erratic when the maximum space between steel surfaces was 0.01 in. It was then decided to increase the spacing to its maximum limit, that is, to where the brass would run out. This was not found to happen until a spacing of the order

(Continued on page 87)

Personal Items

Welton J. Crook, professor of metallurgy at Stanford University, has recently returned from a 15 months' leave of absence, a year of which was spent in study and research on steel making slags at the Ecole Politechnique Roi Carol II in Bucharest, Rumania, for which he received the degree of doctor of engineering.

J. M. Watson, past president of , and metallurgist for Hupp Motor Car Co. for many years, has joined the sales staff of Jones & Laughlin Steel Corp.

Wesley P. Sykes, metallurgical engineer, Cleveland Wire Works, General Electric Co., has been named as the 1937 Edward De Mille Campbell Memorial Lecturer by the American Society for Metals.

Howard R. Weisberger has resigned from Chevrolet Motor Co. and moved to Los Angeles where he expects to open an office of industrial engineering.

James S. Ayling has been elected secretary of the Case Hardening Service Co. He will also serve on the board of directors and continue his former position as sales manager.

George W. Pressell, vice-president, E. F. Houghton & Co., is recovered from an operation for appendicitis and is now back at his desk.

B. G. Constantine has been moved from the main office of the Foxboro Co. to the new office which has recently been opened in Springfield, Mass.

Stanley A. Knisely, director of advertising of Republic Steel Corp., has been elected vice-president of National Industrial Advertisers Association.

Ernest T. Fisher has become associated with the Claude B. Schneible Co., Chicago, as sales engineer covering the territory contiguous to St. Louis.

C. E. Hoyt, formerly executive secretary-treasurer of the American Foundrymen's Association, has been elected to the position of executive vice-president. **Dan M. Avey** will succeed Mr. Hoyt as secretary-treasurer of the Association, and his position as editor of **The Foundry** will be taken over by **Frank G. Steinebach**, formerly managing editor.

R. C. Allen, executive vice-president, Oglebay, Norton & Co., Cleveland, has been nominated for president and director of the American Institute of Mining and Metallurgical Engineers.

Howard Agnew Smith has joined the South Division of Republic Steel Corp. at Canton, Ohio.

Personal Items

William E. Umstattd, president, Timken Roller Bearing Co., has been elected president of the subsidiary, Timken Steel & Tube Co., succeeding **Frederick J. Griffiths**, resigned. **John E. Fick** has been appointed general superintendent of the steel and tube mills, succeeding **K. B. Bowman**, also resigned.

C. D'W. **Gibson,** assistant vice-president, Air Reduction Co., was elected president, and **Elmer H. Smith,** Commercial Gas Co., Minneapolis, was elected vice-president of the International Acetylene Association at the meeting in St. Louis.

D. S. Jacobus, consulting engineer, Babcock & Wilcox Co., New York, was awarded the Morehead Medal of the International Acetylene Association.

J. Emmett Tune has moved to Schenectady, where he is employed in the chemical laboratory of American Locomotive Co.

John A. Malloy has been made resident salesman in charge of the Baltimore office of the Peter A. Frasse & Co., Inc.

F. Connell has been appointed assistant manager of sales, New York district, American Steel & Wire Co.

B. C. Heacock, president, Caterpillar Tractor Co., has been nominated for president of the Illinois Manufacturers' Association.

H. H. Walkup has been transferred from the Office of the Inspector of Naval Materials, Munhall, Pa., to the metallurgical laboratory of the Norfolk Navy Yard, Portsmouth, Va.

E. W. Selman is now with the Surface Combustion Corp. as an engineer on research and development of furnaces.

Eugene J. Ash has resigned as associate metallurgist at Watertown Arsenal to accept a faculty position in the Department of Metal Processing at University of Michigan.

L. Deane Noble is now metallurgical observer in the open-hearth department, Donora Steel Plant, American Steel & Wire Co.

Napier B. Caldwell has been transferred by Joseph T. Ryerson & Son, Inc. to Boston as general salesman.

Donald Broadbelt has been connected with the metallurgical department of Jones & Laughlin Steel Corp. since last spring.

† † †

William Campbell, who has taught many of America's leading metallurgists during 30 years at Columbia University, died on Dec. 16.

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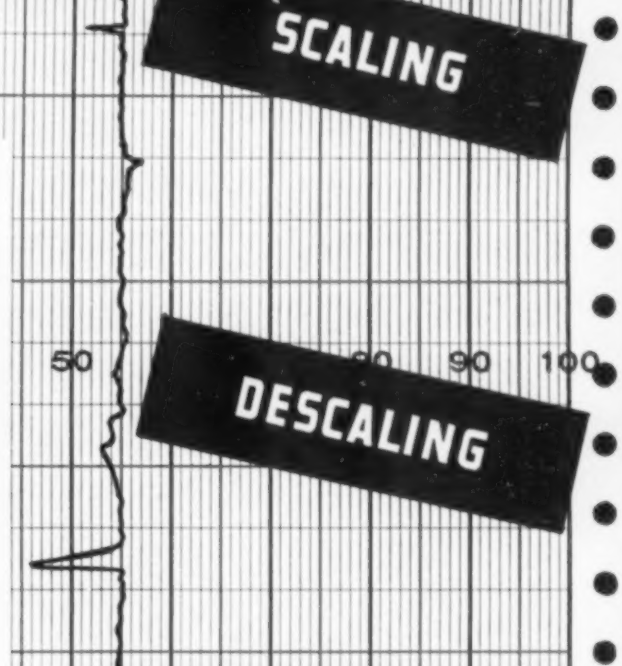

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ATMOSPHERE RECORDER

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Plain bearings

(Continued from page 72)

Now, we know that the formation of solid solutions on the one hand, or of slightly metallic, quasi-chemical compounds on the other hand, depends on the atomic volumes and on the concentration of valence electrons of the constituent metals. A and B will both give solid solutions with C as long as A and B together form solid solutions. This however is contrary to the nature of babbitt, and it is therefore not easy to find a satisfactory metal for C. Thus, if C is a homogeneous alloy or a solid solution of two metals, one alloying with A and the other with B, there is a good chance that they will both form definite compounds with A and B; otherwise, these latter two would also form solid solutions each with each.

This general problem recently received an ingenious solution (patented by the Société d'Electro-Chimie et d'Electro-Métallurgie). For the specific problem of thin babbitted bearings, a heterogeneous alloy is chosen for C composed of two metals in proportions selected so as to be non-miscible in the liquid state — for instance, a copper-lead alloy with one-third lead or a copper-thallium alloy with 30% thallium. The first mentioned alloy is formed of particles of lead disseminated throughout the copper and forms solid solutions with the two metals A and B — the copper with the iron backing (or with the bronze) and the lead with the antifriction alloy. Since the lead particles are encased in the copper matrix, we have adhesion both by alloying action and by mechanical action.

A bearing coated with an antifriction alloy in this way will successfully withstand a very stringent bend test. The bearing is broken open and bent in the opposite direction to its normal curve without harming the bond — providing, of course, that the babbitt is thin; eventual fracture occurs without splitting the lining from the backing. Without the interposition of the intermediate heterogeneous alloy, such a test would be impossible.

This process, of course, is not limited to the fabrication of bearings. Its general principle can be applied whenever it is desired to bond together two metals which do not form solid solutions in their mutual interpenetration zone.

Albert Portevin